UNIVERSITETET I BERGEN

INVESTIGATING HIV SPREADING MECHANISMS AND POLICY ALTERNATIVES IN RUSSIA: A SYSTEM DYNAMICS MODELING APPROACH

Thesis submitted in partial fulfillment of the requirements of Master of Philosophy in System Dynamics (University of Bergen)

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Acknowledgments

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And my last gratitude is for the person, none of this would have ever happened without - **Denis Utochkin**. If there is anything here to be proud of - it's yours.

P.S. I was writing this thesis when my home country Russia started an insane, savage war in Ukraine. It's still going on, innocent people are dying and suffering every day. It took me a long time to stop thinking that writing the thesis is meaningless while this nightmare is happening, and to remind myself that all we have is hope. Hope that science, education, and progress will win eventually, even if doesn't feel like it right now.

Abstract

The HIV epidemic in Russia is a colossal problem that decreases the quality of life for millions of people and causes severe suffering and death. HIV spreading is an ambiguous and multilayered problem that can be considered through a variety of research prisms, ranging from biological and virological to socioeconomic methods. This thesis aims to analyze the HIV spreading in Russia through a system dynamics perspective. The system dynamics approach is an effective tool for structuring, visualizing, and comprehending complex problems. It has proven itself as a thorough method for addressing intricate social problems particularly for studying the spread of infectious diseases.

This study investigates the previously addressed problem by simulating a theoretical model, the structure, connections, and equations of which it was built based on a literature review and data collection from reliable sources.

The simulation results show strong relationships between HIV stigma, testing, and the increase of HIV spreading in Russia. Hence, three policies were suggested and tested in the simulation model: 1) introduction and implementation of sex education on different platforms including educational facilities, news, and mass media; 2) an increase of condom accessibility; and 3) an increase of testing accessibility.

During testing, the sex education policy proved to be the strongest one, although all three proposed policies demonstrated positive results with a significant decrease of new HIV cases each year. Hence, combining the policies seems to be the most effective strategy.

However, these results might not be fully accurate and does not predict the future due to the processes of simplification of the theoretical model and lack of relevant data which would require further research. Nevertheless, this study provides some insight into the HIV epidemic in Russia, which can be further expanded to offer an instrument to better inform policymakers to establish more effective policies against HIV spreading in Russia in a quicker and more efficient manner.

Table of Contents

List of Figures

List of Acronyms

AIDS: Acquired Immune Deficiency Syndrome

CLD: Causal Loop Diagram

HIV: Human Immunodeficiency Virus

HIVnP: HIV-negative Population

HIVpP: HIV-positive Population

IR: Infecting Rate

SD: System Dynamics

SE: Sex Education

TR: Transmission risk

1. Introduction

1.1. Research Background and Justification

The Human Immunodeficiency Virus (HIV) infection is a gradual decrease in the general immunity of a person, as a result, the body loses its ability to resist pathogenic bacteria, the last stage in the development of HIV infection, in which the destruction of vital systems of the body occurs, is Acquired Immune Deficiency Syndrome (AIDS) (Sokolov S.V. & Sokolova A.L., 2019). This virus not only leads to deaths but also has an enormous negative impact on the quality of life of the HIV-positive population.

The situation of HIV spreading in the Russian Federation is worsening each year, and considering the size of its population, it also has a significant impact on global HIV numbers and transmissions. One indication of the urgency of this problem is that with more than one million HIV-positive people, Russia is one of the countries most affected by HIV/AIDS. According to the Joint United Nations Program on HIV/AIDS, Russia has crossed the critical threshold (1% of the country's active population affected, and even 2% in some regions), which qualifies the situation as an epidemic (UNAIDS, 2020). Another illustration of the seriousness of this issue is that the transmission rate of HIV in Russia has been increasing by 10 to 15% yearly (Figure 1) even though the HIV infection rate continues to decline in the rest of Europe. This increase in HIV transmission is comparable to the yearly increase in transmission of HIV in the United States in the 1980s at the height of the AIDS epidemic (Graulich, 2021).

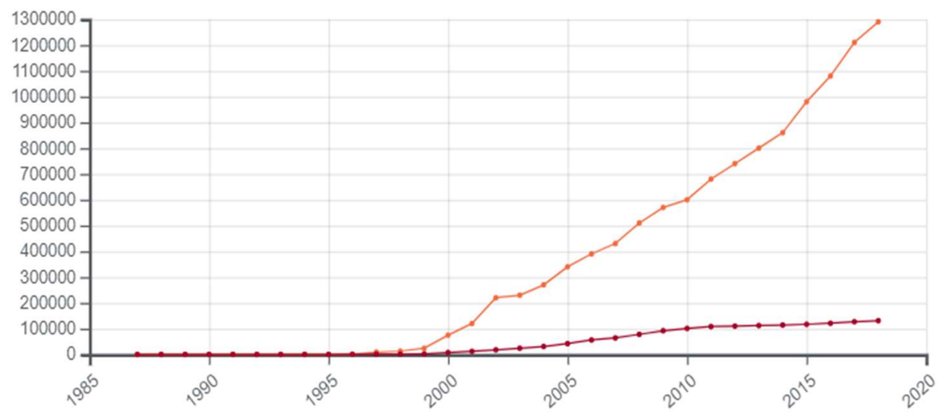

Figure 1 Cumulative number of registered HIV-infected people (orange line) and deaths caused by HIV (red line)

The figure below illustrates a steady growth of HIV-positive people in a time frame from 2015 to 2020, the total number of HIV infected raised on 50% for those five years (Federal Scientific and Methodological Center for the Prevention and Control of AIDS, 2020). In fact, Russia by itself accounts for 4% of all new HIV infections in the world in 2020 (UNAIDS, 2020).

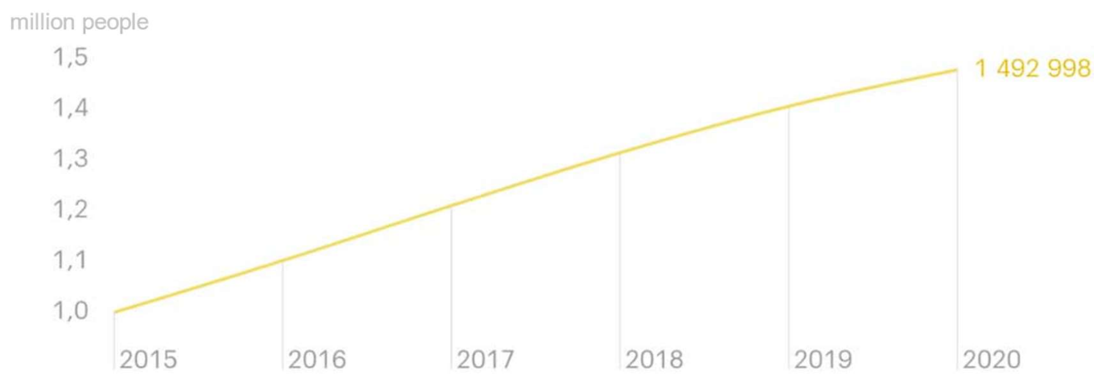

Figure 2 The total number of HIV infected in Russia 2015-2020

It follows from the above that the spread of HIV-AIDS represents a significant issue for Russia. Hence, due to its severe implications to the life quality and health of population, it is crucial to better understand this issue and explore ways to curb the spread of the epidemic.

1.2. Dynamic Problem Definition - the Reference Mode

A reference mode is a behavior-over-time graph that depicts how one or more system variables change over time, often used in problem articulation to describe the dynamic hypothesis, and in model validation to test a model's ability to reproduce realistic behavior patterns (David N. Ford, A system dynamics glossary, 2019). Hence, this chapter presents a reference mode to define the problem examined in this thesis, while Chapter 5.3 refers to it to test the model behavior validity and Chapter 6 uses it for the future scenario and suggested policy analyses.

According to Sterman (2000), reference modes answer the main problem-defining questions such as: What is the historical behavior of the key concepts and variables? What might their behavior be in the future? Therefore, the system variable that was chosen for the reference mode is the total number of HIV-positive people in Russia as one of the main indicators of the HIV epidemic in Russia (Figures 1 and 2).

There are other key indicators of the HIV epidemic that could be used as reference mode, for example the death rate of life expectancy of HIV-AIDS positive population. However, the total number of HIV-positive people was considered the ideal reference indicator for this research. The reason for this is that deaths caused by HIV are not that obvious, the virus influences the life of the infected people on many different levels, such as increased risk of having STDs, tuberculosis, and other diseases; drug abuse; suicides; etc. This means HIV influences the quality of life and causes deaths not just directly but through many indirect effects. However, it will not be counted as an HIV-caused death in official sources, which is why such data would fail to encompass the true death count.

And finally, another reason why the total number of HIV-positive people was chosen to reflect the HIV epidemic is the existing policies. The government concentrates all its policies and funds on dealing with people who already have HIV and overlooks the underlying causes of the problem – HIV spreading. Hence, the current study is focused on decreasing the infection rate, which is why the checkpoint (reference mode) is the total number of the infected population.

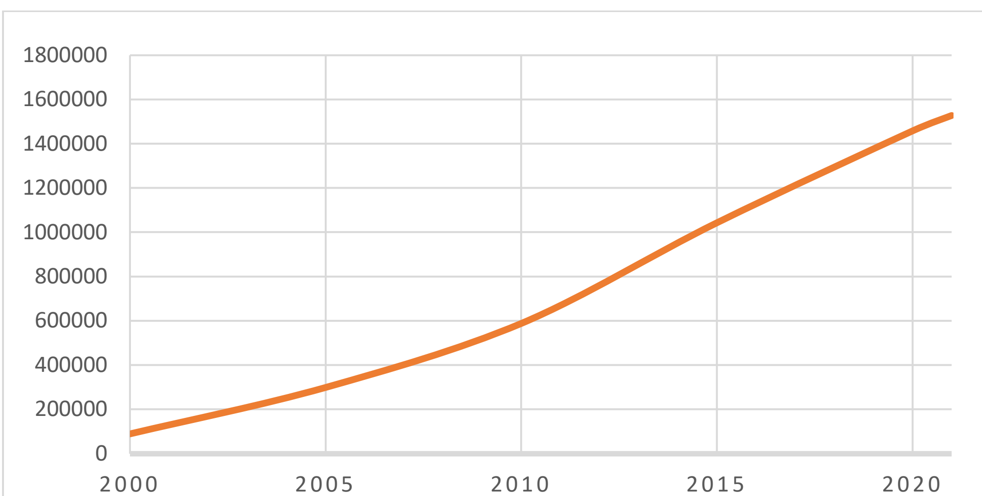

Figure 3 HIV-positive population total - historical data

In the model, the reference variable is HIVpP total Data which contains the combined quantitative data from The Federal Scientific and Methodological Center for the Prevention[1] and Control of AIDS and The Federal State Statistics Service[2] (Figure 3).

Nevertheless, the numbers are not completely accurate due to several reasons, one of them is that the main agencies (Ministry of Health of the Russian Federation, Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing) have different numbers in their reports "The difference in the data is related to the peculiarities of registering infected population" (Pokrovski, 2018). Another reason is the stigmatization of HIV at all levels, including governmental (more about it in Chapter 2), which often makes the numbers unclear and underestimated. It is important to mention that the reference mode is about the behavior of the variable, not its numbers: "You don't need quantitative data to capture the dynamics in the reference modes" (Sterman, 2000). However, there is available data for the parameter that was picked for the reference mode in this study which provides an idea of the behavior trends of the total HIV positive population.

1.3. Research Objective and Research Questions

The focus of this research is to explore the dynamic behavior of the HIV-spreading mechanisms in Russia, clarify the cause-and-effect relationships between the internal components of this system, and identify potential policy options that could alleviate this problem. Hence, the study goal was divided into two distinct research objectives and the following research questions:

Objective 1. Identify the key factors and their interactions of the HIV epidemic in Russia.

1.1. What are the key feedback mechanisms responsible for the constant growth of HIV spreading in Russia?

1.2. Which mechanisms or key factors contribute more to the spread of HIV in Russia?

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[1] Federal Research and Methodological Centre for the Prevention and Control of AIDS. URL http://www.hivrussia.info/

[2] The Federal State Statistics Service. URL https://rosstat.gov.ru/

Objective 2. Develop potential policy suggestions to help reduce the HIV spreading level in Russia.

2.1. What are the potential policy alternatives that can help reduce or slow down HIV spreading?

2.2. Which insights can be derived from possible future scenarios and policy simulations?

2.3. Which further challenges and limitations should be taken into consideration when it comes to policy implementation?

1.4. Research Methodology and Strategy

System Dynamics (SD) is the primary research methodology applied in this thesis. SD is a complex, interdisciplinary study that is defined as:

- use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behavior (Lane, 2017).
- a structural theory of dynamic systems (Lane, 1999).
- an iterative and interdisciplinary process, which views problems holistically (Palmer, 2017).

Given that this study is aimed to analyze the HIV epidemic in Russia, its driving factors, and possible solutions, this research develops a proposed HIV-spreading tool in the form of a dynamic simulation model to achieve the posed objectives and address the research questions. The model structure and its variables were based on the analysis of relevant literature and data collection. The thesis uses a mixed-methods research strategy that uses both qualitative and quantitative approaches (Denscombe, 2012). Nevertheless, taking into consideration that many variables were challenging to be calculated or found in open sources, the model itself should be considered more qualitative, rather than quantitative.

The HIV epidemic is a highly complex, multi-faceted system, that is why SD can help with analyzing the system, its structure, and mechanisms. Moreover, SD has previously been used to comprehend and test potential policy solutions for other epidemics or public health problems (Dangerfield et al., 2001; Darabi and Hosseinichimeh, 2020; Ghaffarzadegan and Rahmandad, 2020). SD has been widely used to study social problems and humanitarian crises. SD can shed light on how to improve humanitarian response to meet the diverse needs of populations (Gonçalves, 2011; Rocca, 2021; etc.). Thus, it is very important to mention that SD gives an opportunity not only to analyze the effects and causes of the system's structure and behaviors, but also to explore potential future scenario results, and policy design and testing.

1.5. Data Collection

Table 1 Data collection: sources, categories, use

Category	Sources examples	Type of data	Collected data	Use in the model build
Demographic data	The Federal State Statistics Service.	Quantitative	The total population number, age fractions, birth rate, death rate, etc.	Values of general population variables
Epidemiological data	The Federal Scientific and Methodological Center for the Prevention and Control of AIDS; Ministry of Health of the Russian Federation.	Quantitative	Numbers of HIV-positive and HIV-negative populations, the infectivity of sex contacts, etc.	Values of HIV-related variables
	Sokolov S. V., Sokolova A. L. HIV incidence in Russia: SIR epidemic model-based analysis, 2019; Fox J, Fidler S. Sexual transmission of HIV, 2010.	Qualitative	The process of infecting the population, the main reasons for HIV spreading, etc.	Casual structure, connections between variables, equations
Human behavior data	Kok S. et al. Optimizing an HIV testing program using a system dynamics model of the continuum of care, 2015; Earnshaw, V. A., & Chaudoir, S. R. From conceptualizing to measuring HIV stigma: A review of HIV stigma mechanism measures, 2009.	Qualitative	Stigma, causes, and effects of HIV stigmatization; risk behavior; condom use; willingness to test; etc.	Casual structure, connections between variables, equations

Modelers have an ethical responsibility to pursue the modeling process with rigor and integrity (Sterman, 2000). Hence, this study satisfies the five principles of research ethics (Smith, 2003), does not use any primary data or publicly unavailable information, adheres to transparency, and is honest with its assumptions.

The data collected during the model development for this thesis can be divided into three categories: demographic data, epidemiological data, and human behavior data. The last two helped to build the structure of the model, connections, and equations, while the first one simply gave information for the population variables. Some of the relevant specific examples of data collection sources, their categories, and contributions are presented in the table above (Table 1).

2. Literature Review

This chapter presents an overview of the relevant literature to this study. As it was mentioned before, the system dynamic method operates on the basis of qualitative and quantitative data. Thus, the information gained from the reviewed literature provided a platform for the general concepts of the thesis and helped to develop a reasonable structure for the theoretical SD model.

The papers that mainly were used for investigating the nature of HIV spread in Russia and also constructg the relevant system dynamics model are "From conceptualizing to measuring HIV stigma: a review of HIV stigma mechanism measures" (Earnshaw & Chaudoir, 2009); "A system dynamics model of the continuum of care for HIV" (Kok, 2012); "HIV and Substance Use Stigma, Intersectional Stigma and Healthcare Among HIV-Positive PWID in Russia" (Vetrova, 2021); and HIV incidence in Russia: SIR epidemic model-based analysis (Sokolov & Sokolova, 2019). Other authors that significantly helped with understanding the structure and regularities of the HIV epidemic in Russia and globally are: Balabanova et al., 2006; Amirkhanian et al., 2011; Fox and Fidler, 2010; King et al., 2013; Edelman et al., 2017; Sakhratulaeva, 2017; Gonçalves, 2019.

2.1. Key thesis topics based on literature review

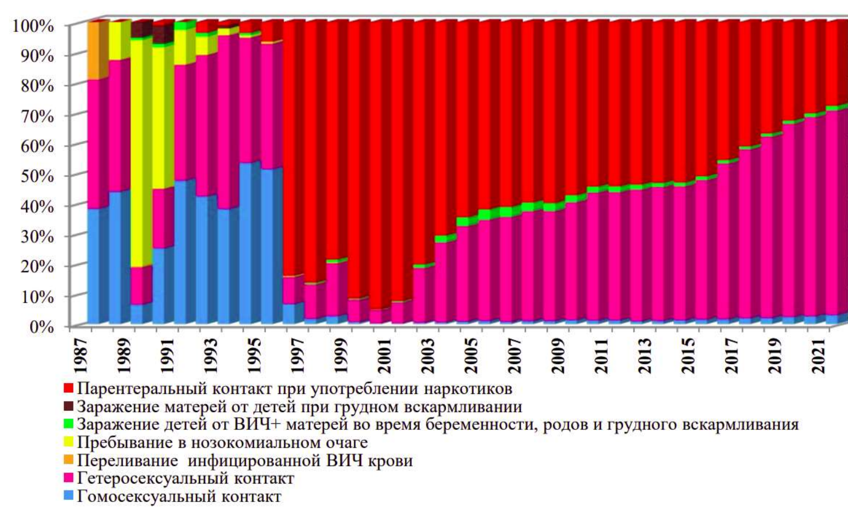


Figure 4 Distribution of HIV-infected people in Russia by main known

According to the Federal Scientific and Methodological Center for the Prevention and Control of AIDS, in 2021 sexual transmission caused a little more than 70% of new HIV cases.

During the last 20 years, sexual contact became the number one way of getting HIV, moving drug injections to second place (Figure 4. The red colored bars – drug use, the pink colored bars – heterosexual contacts, the blue colored bars – homosexual contacts). That is why this research project is focused on the sexual transmission of HIV that strongly connected with HIV stigma.

Stigma defined as a process of labeling, stereotyping, separating, experiencing loss of status for the stigmatized, and exercising of power. (Link & Phelan, 2001). Stigma and discrimination hinder accessing necessary HIV services for marginalized groups.

Indeed, there is evidence of a high level of HIV stigma in Russia, a large number of papers declares a high level of HIV stigma in Russia (Balabanova et al., 2006; Amirkhanian et al., 2011; King et al., 2013; Edelman et al., 2017).

It discourages people from using services for HIV prevention and detection and produces stereotypes, prejudice, and discrimination towards HIV-infected people and people who are in touch with them. Hence, HIV-positive individuals may also experience stigma due to other stigmatized characteristics such as substance use, sex work, and minority sexual or gender identities (Vetrova, 2021).

HIV stigma impacts a variety of psychological, behavioral, and health outcomes for both people who are HIV infected and people who are HIV uninfected (Earnshaw & Chaudoir, 2009). "HIV Stigma Framework" - a model built by Earnshaw and Chaudoir, highlights stigma's mechanisms and outcomes. According to their work all components of this system are connected and impact each other from both uninfected and infected groups (Figure 5). "Through the mechanisms of prejudice, stereotypes, and discrimination, the existence of a stigma can impact a variety of psychological, behavioral, and health outcomes for both people who are HIV infected and people who are HIV uninfected" (Earnshaw & Chaudoir, 2009).

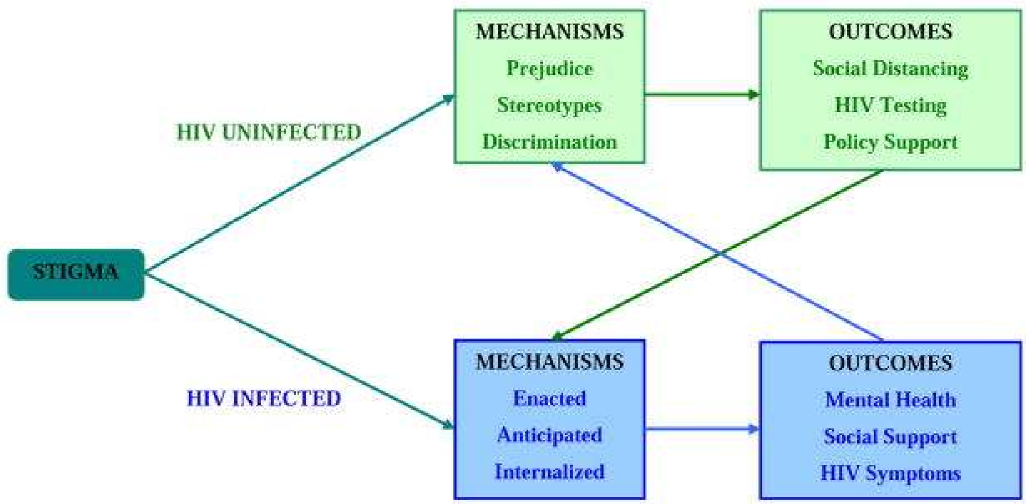


Figure 5 Model of HIV stigma mechanisms

Therefore, stigma does not only have a detrimental effect on people's lives, both HIV-positive and HIV-negative, but it is also a major factor in the HIV epidemic due to its links to worse mental health, higher risk sexual behaviors, non-adherence to medicine, and lack of care retention. In this model, the main outcomes of the stigmas mechanism are a lower testing rate and a higher unprotected sex rate.

For these reasons, in this research, HIV stigma is considered the main catalyst of the HIV epidemic in Russia. HIV awareness in Russia is a very weak point, up to nowadays conversation about sex is a taboo in Russian society. Moreover, sex education is perceived as a "propaganda of lechery" (Sakhratulaeva, 2017). While there is no sex education in schools and a pervasive, multigenerational taboo, there are some in the media who are trying to spread awareness on their platforms. For instance, one of the most famous YouTubers and journalists Yuri Dud made a video about the HIV epidemic in Russia that has already been watched by more than 20 million people. However, in a government-controlled country like Russia, it is hard to do something without the government intervening. Recently, this journalist was fined for working on an article that was classified as "gay propaganda". Which, in this case, meant having an openly gay person as one of the interviewees (Reuters, July 2022). Therefore, the HIV epidemic is growing silently in the shade of the ultra-conservative government policies that are also supported by the powerful Russian Orthodox Church.

2.2. System Dynamics research on HIV

A large amount of work conducted by the Vancouver HIV Testing Program Modelling Group describes the importance of having effective HIV testing throw the SD framework (Kok et al., 2015). The picture below is a CLD from their study, and it illustrates two basic but significant loops of the HIV-spreading system and how the testing system affects them (Figure 6). HIV testing is an external factor that helps to slow down the infection rate. In simple words awareness leads to resolution, the more people who have been diagnosed, the more HIV-infected people who understand their status, will seek treatment, and follow the safety guidelines. Thus, it not only decreases patient morbidity and mortality but also reduces the number of new HIV infections. This loop is laid in the main structure of the current thesis model and its policy suggestions.

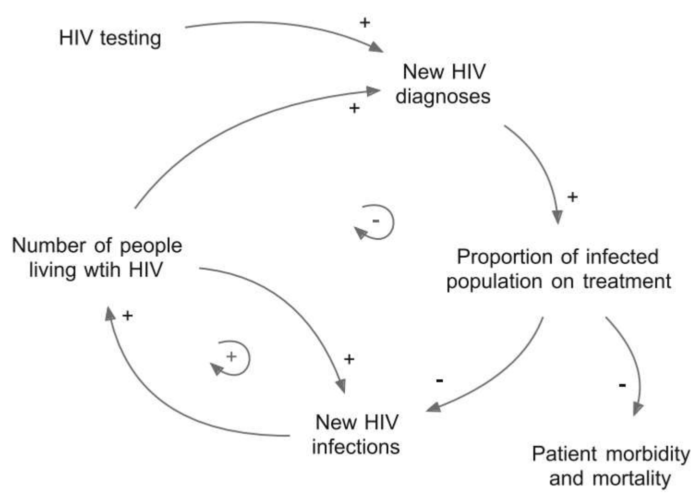


Figure 6 A simple CLD of the continuum of HIV care

Some other works that look at HIV/AIDS spreading with SD framework were analyzed for this thesis. They all use a SIR model as a base model and develop it in different directions. Thus, the study "Using System Dynamics to model the HIV/AIDS epidemic in Botswana and Uganda" considers several other current and suggested policies (Howell et al., 2013). In addition to condom availability and educational campaigns, that are considered in this work, they operate with policies such as abstinence only, increased availability of ARTs, circumcision, and family planning. The work of Weeks et al. in concluding comes to a reducing HIV incidence strategy that includes offering HIV testing in shelters and building partnerships between community-based institutions to reduce the stigma of HIV in the community (Weeks et al., 2017).

3. Feedback Description and Analysis

3.1. Description

The essence of system dynamics modeling is discovering and representing the feedback processes, which, along with stock and flow structures, time delays, and nonlinearities, determine the dynamics of a system (Sterman, 2000). This chapter describes the main feedback loops of the model and the HIV-spreading system itself. Feedback is one of the most important concepts in System Dynamics, hence, there is always feedback in any system where at least two components are connected with each other. All systems, no matter how complex, consist of networks of positive and negative feedbacks, and all dynamics arise from the interaction of these loops with one another (Sterman, 2000).

There are some key system dynamics definitions that will be used further in the study (David N. Ford, A system dynamics glossary, 2019):

Feedback: when the effect of a causal impact comes back to influence the original cause of that effect. A feedback loop is a sequence of variables and causal links that creates a closed ring of causal influences.

CLD (causal loop diagram): a tool that represents closed loops of cause-effect linkages (causal links) as a diagram intended to capture how the system variables interrelate and how external variables impact them. Causal loop diagrams identify and label feedback loops to facilitate understanding, dynamic reasoning, and formal modeling.

Reinforcing feedback loop: a feedback loop in which the sum effect of the causal links tends to strengthen (reinforce) the movement of variable values in a given direction due to positive feedback.

Balancing feedback loop: a feedback loop in which the resultant effect of the causal links over time limits or constrains the movement of variables. Balancing loops seek equilibrium, trying to bring stocks to the desired state and keep them there.

3.2. Main Feedback Loops of the Model

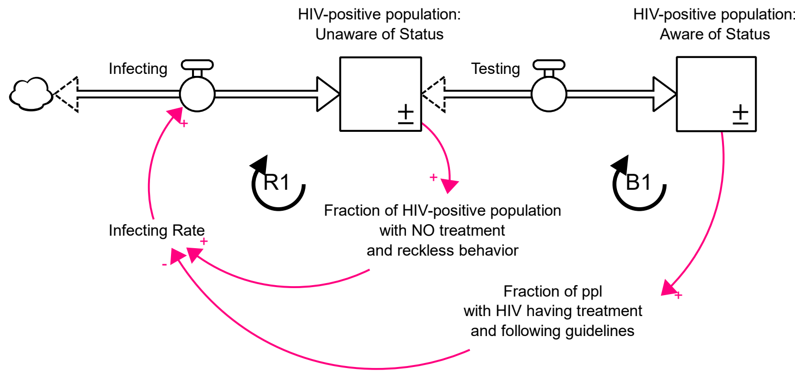


Figure 7 CLD of HIV infecting and testing

The CLD above is a simplified map that illustrates the core of the model and its two main feedback loops (Figure 7). Links between variables have their own polarities, which show how the affected variable changes after the affecting variable changes. The polarities can be either positive (+), when the change in the variables are in the same direction, or negative (-), when the change in the variables are in the opposite directionsit

R1 is a reinforcing (positive) loop which means this loop tends to amplify and reinforce the process inside it. In this case, it intensifies Infecting and increases the number of new HIV cases each year. In other words, an increase in Infecting rate leads to an increase in new HIV cases, which increases the number of HIV-positive population. Hence, the more people are infected and not aware of it, the grater the chances to spread the disease, so the loop is closing by increasing the Infecting Rate. The R1 is a positive reinforcing loop, that should produce exponential growth (Figure 8).

B1 is a balancing (negative) loop which means this loop is self-correcting and counteracting to changes. This might seem contradictory, but the B1 loop in general means that a bigger Infecting number leads to a smaller Infecting number and vice versa – than fewer people are getting infected, then more people are getting infected next time. Step by step it looks like this: an increase in Infecting leads to more new HIV cases, it causes an increase in testing and the number of HIV-positive population, which means the Fraction of the Aware population is bigger now too. However, an increase in this fraction means more people are now receiving treatment and/or are now behaving more carefully (having safe sex). This means fewer people get infected. As was mentioned before balancing loops always try to put the system to equilibrium by counteracting its changes, this way the B1 loop should produce exponential decline, as balancing loops typically do. (Figure 8).

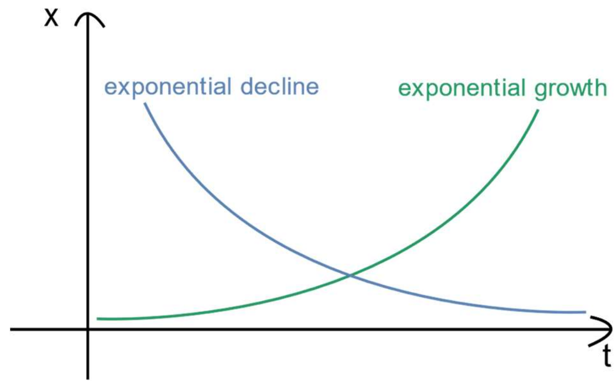


Figure 8 Exponential decline and exponential growth

So, why is there a "self-correcting" mechanism the number of infected people is still growing every year? The answer might be – because the R1 loop is dominating, while the B1 loop is too weak. Therefore, to fix this problem the flow that feeds the R1 loop should be decreased, and the flow that feeds B1loop should be increased. This means an increase of the testing flow speed and decrease of the infecting flow speed (Figure 7).

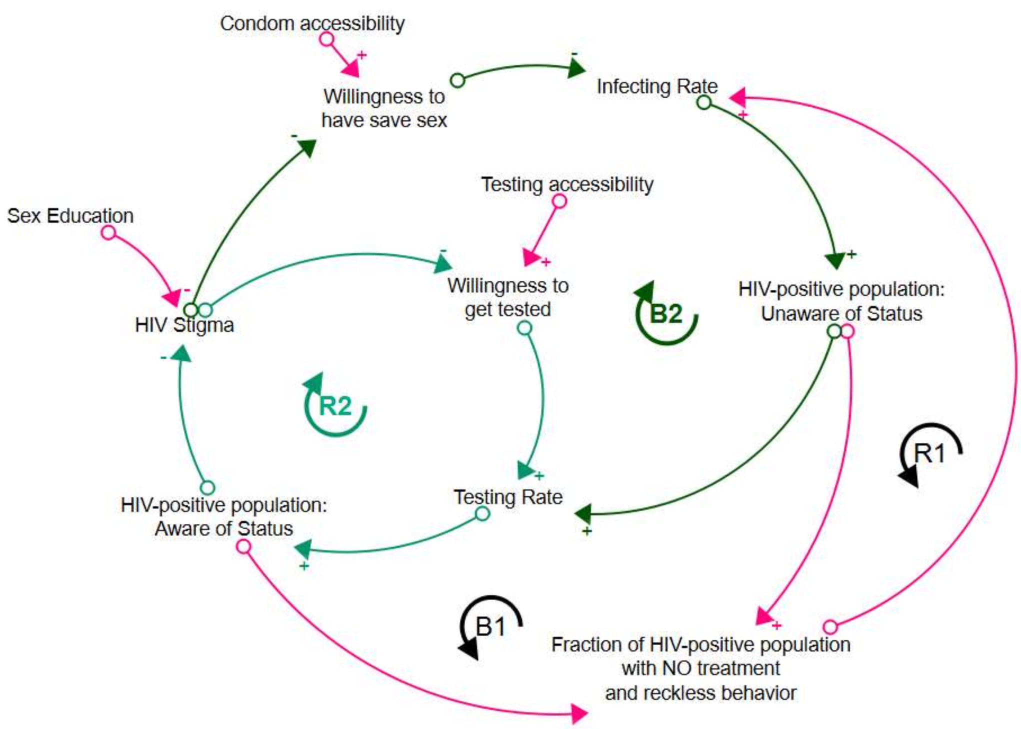


Figure 9 CLD of the model with its policies

Besides the two loops already described (R1 and B1), another two loops are based on the process of HIV stigma decreasing the population’s desire to get tested and to use condoms during sex. Thus, these effects are parts of two loops presented in the CLD below (Figure 9).

R2 is a loop that works based on the cohesion mechanism of a society – the bigger number of HIV-infected people aware of their status the more friends and relatives are aware about HIV, so this problem is more often a topic of conversations, therefore the smaller the HIV stigma is in society. Then, a decrease in stigma leads to an increase of testing rate and it eventually increases the percentage of the aware HIV-positive population. Therefore, if there is an increase in the aware of status population (or the testing), this will lead to an even further increase to this the next time around.

B2 is a loop that gets activated by the connections between HIV Stigma level and willingness of the people to have protected sex. The lower the stigma, the more people are aware of HIV and thus want to follow guidelines and have safe sex. This leads to a decrease in infecting rate which decreases the size of the Unaware population and increases the size of the Aware population. Then it ends up with an increase of stigma.

4. Model Description

This chapter provides a detailed description of the constructed model. The model is a tool that allows answering the research questions for this study. The simulation model shows the core processes driving HIV spreading and captures a representation of real-life behavior of the HIV-spreading system.

4.1. Model Set-up and Boundaries

A system is not isolated and connected to an enormous number of other systems and their parts. That is why it is important to establish system boundaries.

The table below presents examples of the key variables divided into endogenous, exogenous, and excluded.

Table 2 Model Boundary

Endogenously added	Exogenously added	Excluded
Stigma level	Normal stigma	Types of stigmas
Testing rate	Testing accessibility	Testing cost
SE population	Weight of SE	SE cost
Infecting rate	Death rate	Deaths by causes

The model settings are the following:

Time horizon - The model runs for 40 years, from 2000 to 2050. It is about 25 years from nowadays in both directions: the future and the past. This time gap is enough to cover past accumulations and changes, but also to make some realistic future scenarios.

Time units: years.

Delta Time (DT): 1/12 (a monthly timestep).

Integration method: Euler.

4.2. Model Structure

This section overviews the model's main components, boundaries, and assumptions. Technical specifications can be found in the Stella ".stmx" file which is attached to this thesis and its full documentation is shown in the Appendix.

As mentioned before, the developed model captures the mechanisms of HIV spreading in Russian Federation. In other words, it is a theoretical representation of the real HIV epidemic in Russia, with its main components, rules, and cause-and-effect relationships.

Figure 10 SIR structure

Most of the disease-spreading models are built based on the validated mathematical model for epidemic spread named the SIR model (Kermack & McKendrick, 1927), where the population is divided into three stocks: Susceptible (S), Infected (I), and Recovered (R) (Figure 10). However, in the current model Recovered state does not have same conditions in this model because HIV is not completely treatable yet, which means the Infected stock does not have a flow that move population back to Susceptible. Therefore, the loop that usually can be observed in disease-spreading models does not exist in HIV-spreading models.

There is a simplified map of the model below (Figure 11) that shows its population stocks, a detailed explanation of the sectors is in the next chapter. The susceptible population in the model is uninfected people between 16 and 50 years old, this group was established as the most sexually active group.

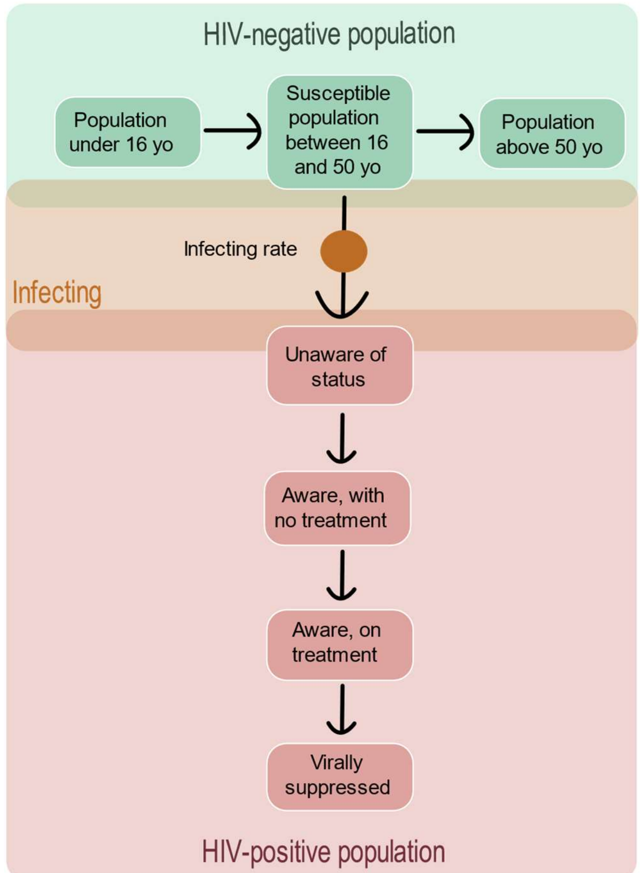


Figure 11 Simplified map of HIV spreading in the model

The model is concentrated on the sexual transmission of HIV and its factors as this is the main cause of HIV spread in Russia. Therefore, the infecting rate is influenced by the amount of unsafe sex, which is influenced by: HIV stigma, sex education, mass media and news coverage, accessibility of testing, and accessibility of sexual protection products (a detailed explanation of relationships and effects is in chapter 4.6. Feedback analysis).

4.3. Model Detailed Sector Descriptions

The model has 10 main sectors, that are divided into three groups based on their themes:

The population sectors (colored in black) show the main population groups and their development during HIV spreading, this group consists of the three following sectors.

1. The sector "HIV-negative population" has three population stocks divided by age segments. This model focuses on people between 16 and 50 years old, as the most sexually active group, hence the main model is connected only with the second stock (Figure 12).

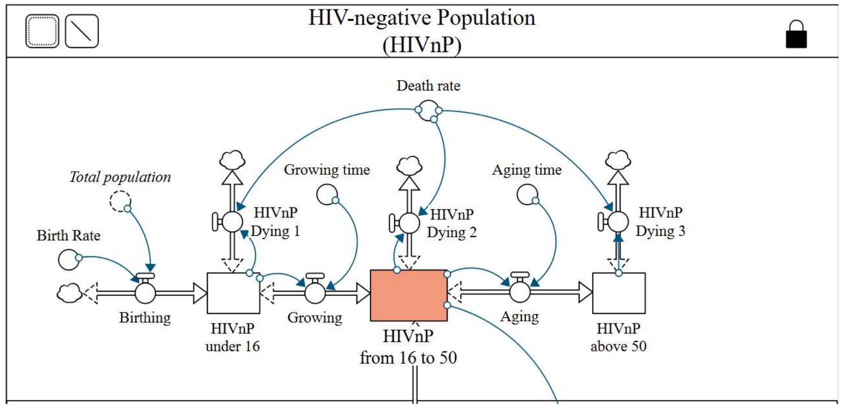


Figure 12 HIV-negative Population sector

2. The "Infecting" sector (Figure 13) The sector includes the Susceptible people (the HIV-negative population that can be infected) and Contagious people (the population currently infected and not virally suppressed). Infecting rate is a sum of new HIV cases caused by sex transmission and other cases that are considered external to this model.

Another important variable of the sector is Risk behavior, it's a table function that represents a correlation between the unaware HIV-positive population and their risky behavior (such as unprotected sex).

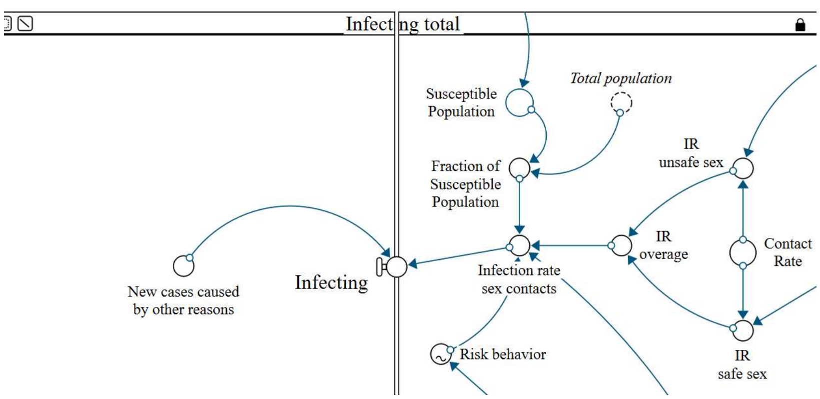


Figure 13 Infecting total sector

3. The "HIV-positive population" (Figure 14) contains four population group stocks, all of them HIV-positive, but the first stock has people who are not aware of their status; after testing the second stock accumulates people who are aware of their status but receive no treatment; the third stock contains population on treatment, but still contagious; the fourth and final stock represents the safest, not contagious HIV-positive population.

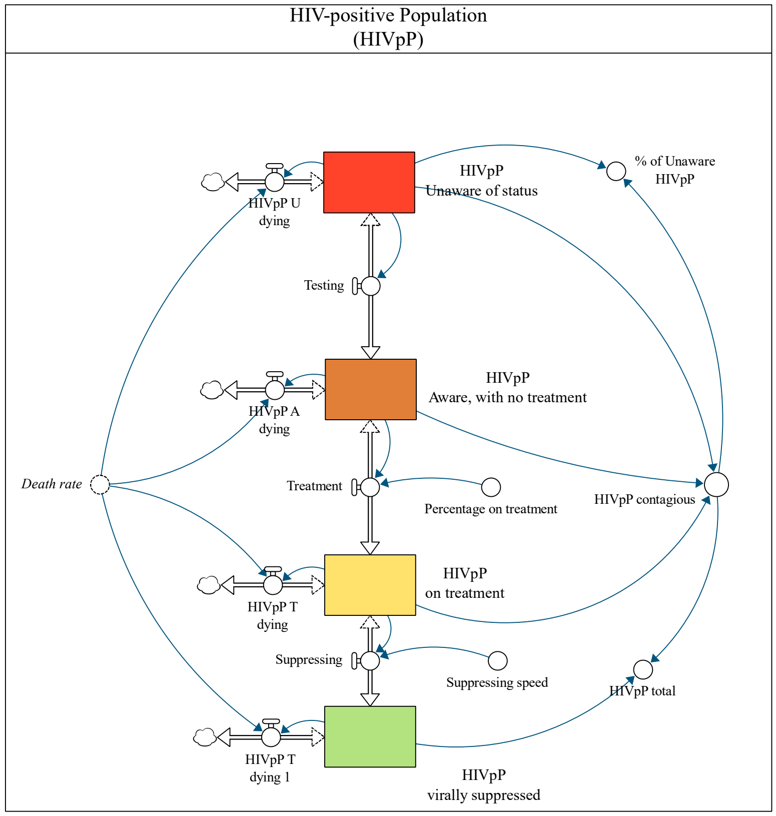


Figure 14 HIV-positive Population sector

The next three sectors (dark red frames) contain the most important processes for this study, which will have a significant impact on the system's behavior.

4. The "Infecting by sex contacts" (Figure 15) includes variables that calculate the infecting rate of both safe and unsafe sex. The probability of having protected sex is based on two factors: Protection products accessibility and Willingness to have safe sex, both are multiplied by their weights.

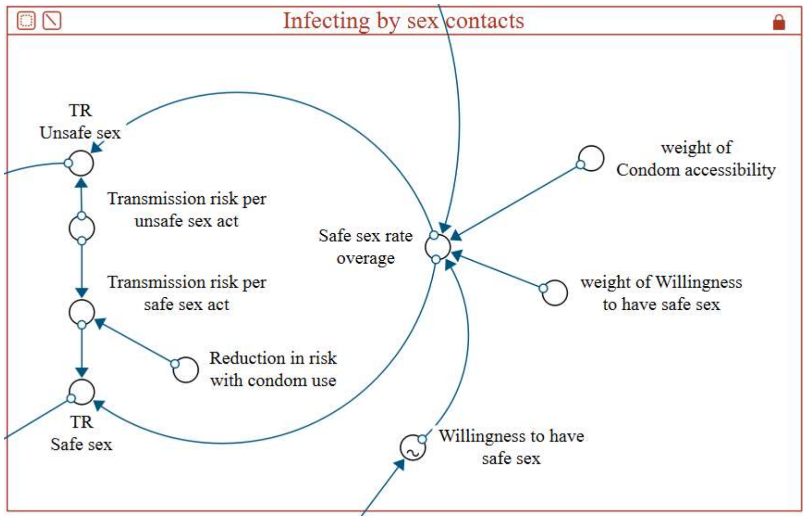


Figure 15 Infecting by sex contacts sector

5. The “Testing rate” (Figure 16) sector calculates the testing rate based on the Stigma and the Informing sectors. Similar to the previous sector, there are two factors (Testing accessibility and Willingness to test) that are multiplied by their weights.

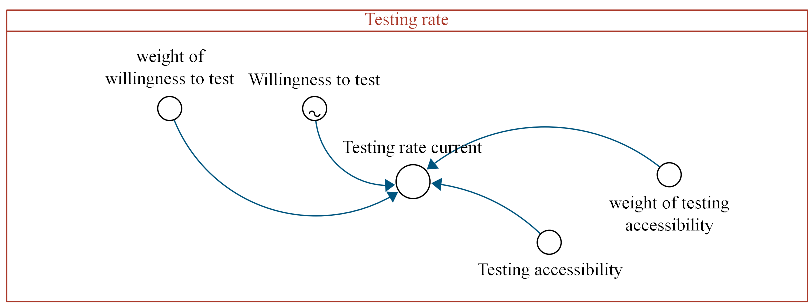


Figure 16 Testing rate sector

6. The “Stigma” (Figure 17) is the core of the whole model and the target of the main policies. The Stigma is represented as a stock with its initial value – Normal stigma (normal here means the usual, the typical, but not as normal in an approving positive way). The level of the Stigma can be changed after switching the SE policy.

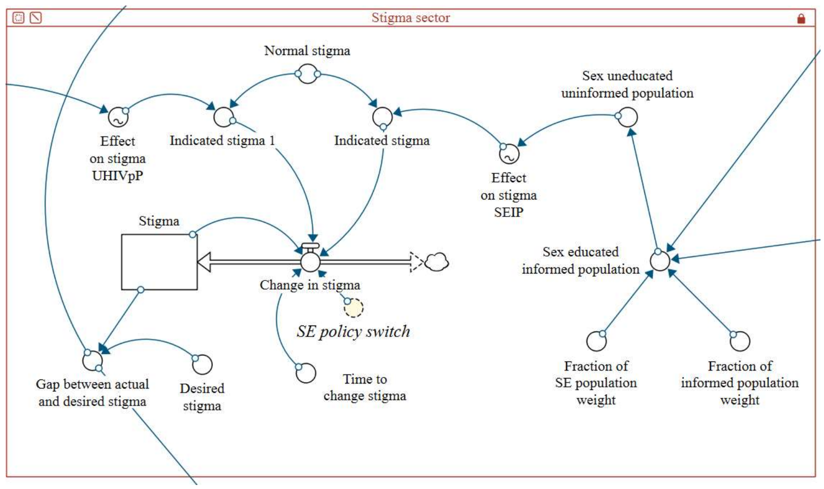


Figure 17 Stigma sector

The Stigma is the central part of the system in the model, it has a significant effect on HIV infection growth and at the same time depends on the population behavior (Figure 12).

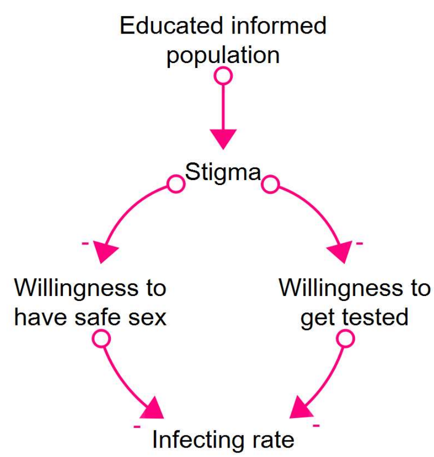


Figure 18 Cause and effect relationships of the Stigma in the model

The third group includes four policy sectors (pink frames). Two of them are external:

7. The "Protection products accessibility" policy (Figure 19) simply changes the policy of providing free sexual protection products from the old one (which is zero percent) to the new one (one hundred percent).

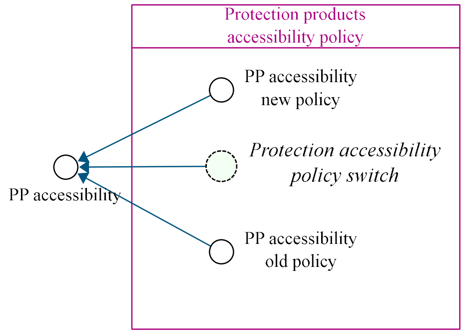


Figure 19 Protection products accessibility policy sector

8. The “Testing accessibility” policy (Figure 20), similarly to the previous sector, changes the policy of providing a free, anonymous, convenient testing system from the old one (which is zero percent) to the new one (one hundred percent).

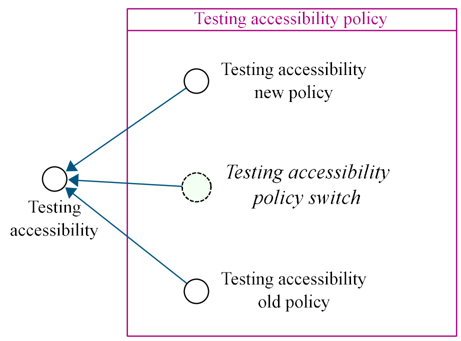


Figure 20 Testing accessibility policy sector

Another two sectors are the main policies that the study is focused on:

9. The “Sex education” policy (Figure 21) is a simplified recreation of the population sector of the model. There are two main stocks Population without SE and SE Population, the flow from the first stock to the second one is Getting SE, and it starts working only after the SE policy switch is on. Hence, the information is getting old or forgotten by people, so the SE population has its outflow named Forgetting SE. The main effects of SE knowledge that the study are interested in are people following save guidelines, using condoms, getting tested regularly, being against any discriminations or stigmatizations of HIV-positive people.

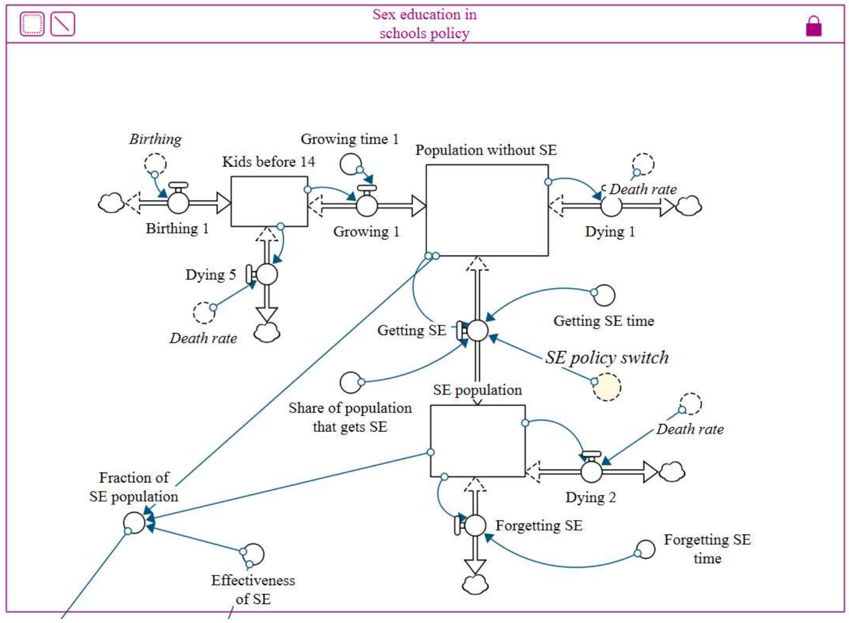


Figure 21 Sex education policy sector

10. The "Informing" policy (Figure 22) is very similar to the Sex Education policy sector. The only difference between the two sectors is that Informing can be reminding about forgotten information, whereas SE represents a learning program at school where the students have no pre-existing information about sex. That is why an outflow of the second stock is also an inflow for the first stock in this sector.

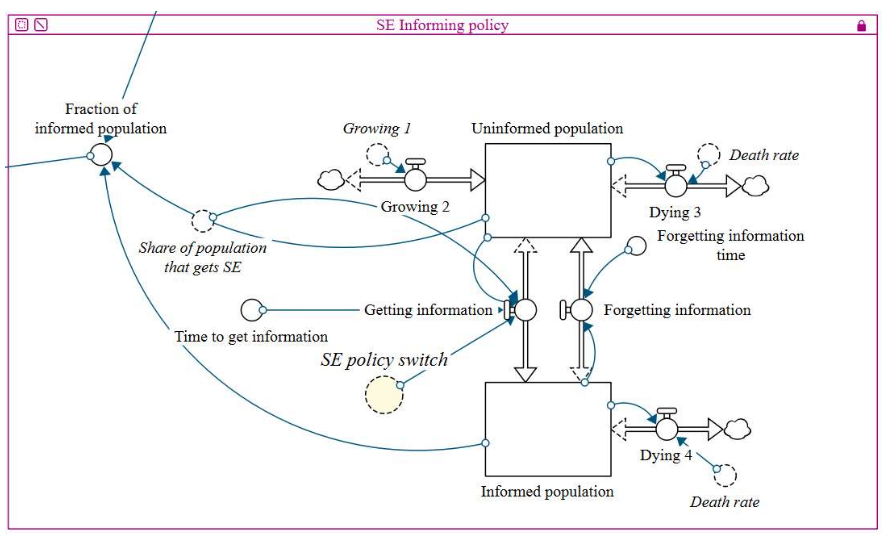


Figure 22 Informing policy sector

4.4. Model Assumptions

Effects and its table functions

One of the main assumptions in the developed model is its effect variables. For instance, the variables that are based on the policies: Effects on stigma, Willingness to have safe sex, and Willingness to test. These variables are intermediate segments between an abstract value of Stigma level (dimensionless) and concrete model parameters (Informed educated population, Percentage of HIV-positive diagnosed population, Safe sex rate, and Testing rate). Those parameters are not connected to each other directly in the model, the picture below is a simplified representation of their connections (Figure 23).

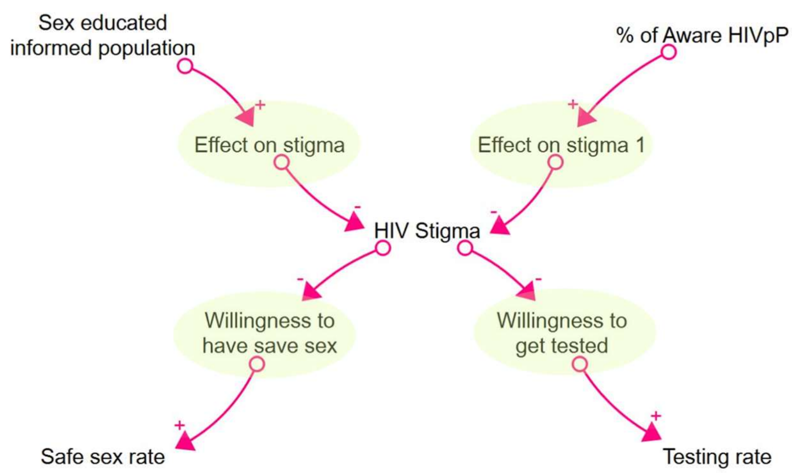


Figure 23 Connections of the variables with a table function

More often, nonlinear relationships are captured using lookup or table functions, where the relationship is specified as a table of values for the independent and dependent variables (Sterman, 2000). Hence, those variables are calculated with a graphical function.

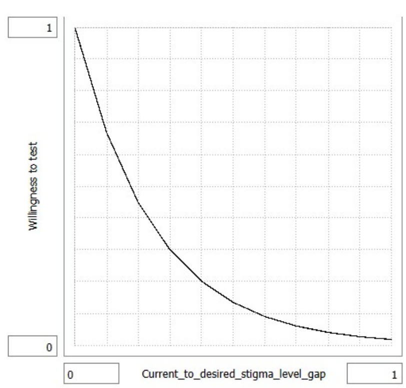


Figure 24 Willingness to get tested

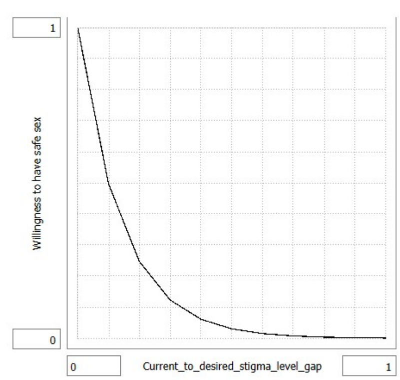


Figure 25 Willingness to have safe sex

Willingness to have safe sex and Willingness to test have the same shape in their graphical function – an exponential decay (Figure 24 and 25). It simply means that the bigger the input (Current stigma level to desire stigma level gap) the smaller the output (Willingness to have safe sex and Willingness to test). Therefore, the model assumes that stigma levels change the desire of people to get tested and/or to have safe sex behavior in opposite direction (as it was described in Chapter 2. Literature Review, stigma goes up and willingness goes down). The function lines are not straight because the changes in collective minds do not happen immediately.

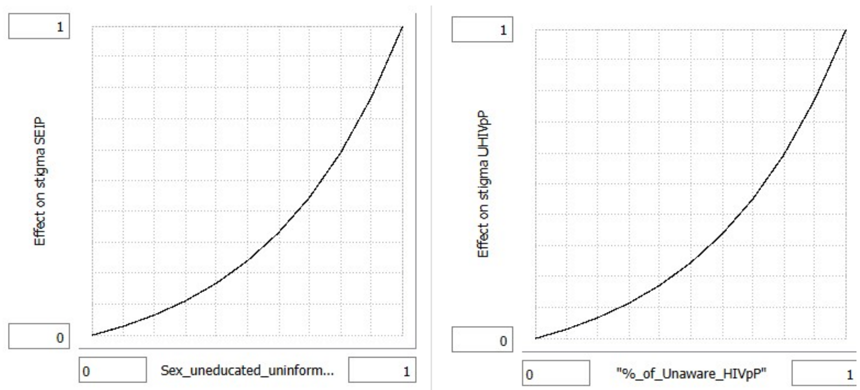


Figure 26 Table functions of effects on stigma

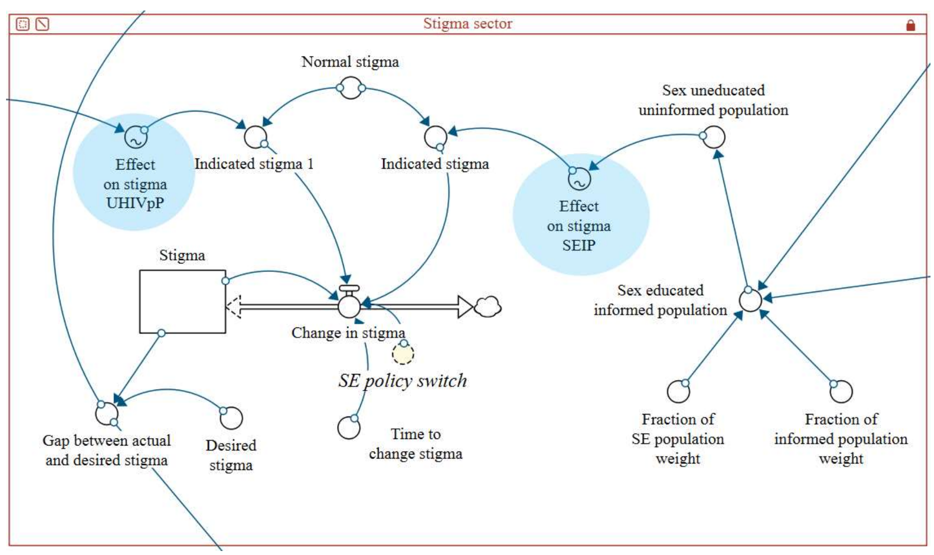
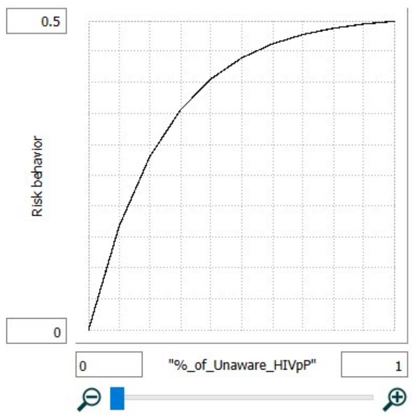


Figure 27 Effects on stigma in Stigma section

Both effects on the Stigma have an exponential growth shape in its functions (Figure 26). It represents the effect of not informed population without SE (that is based on SE and Informing sectors) on Indicated stigma (that changes the Stigma) (Figure 27). In other words, this function is built on an assumption that was mentioned in Chapter 2 – the bigger the size of sex educated and informed population, the smaller the level of HIV stigma.

Another variable with a nonlinear function in the model is the Risk behavior, which calculates the effect of the percentage of HIV-positive people who are not aware of their status (Figure 30). Presumably, the HIV-negative population is more careful with sexual relationships and sex protection. Therefore, the bigger percentage of the unaware HIV-positive population leads to an increase in the risk behavior, which leads to an increase in infection by sexual contact.



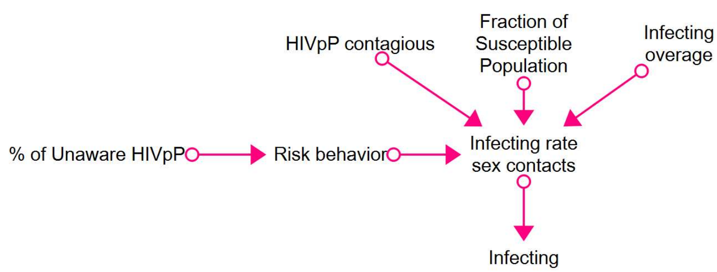


Figure 28 Risk behavior graphical function   *Figure 29 Risk behavior and its connection in the model*

Weights of parameters

A weight in statistical terms is defined as a coefficient assigned to a number in a computation, for example when determining an average, to make the number's effect on the computation reflect its importance (OECD glossary of statistical terms). There are four variables that have their weights in the model: PP accessibility, Willingness to have safe sex, Willingness to test, and Testing accessibility (Figure 32).

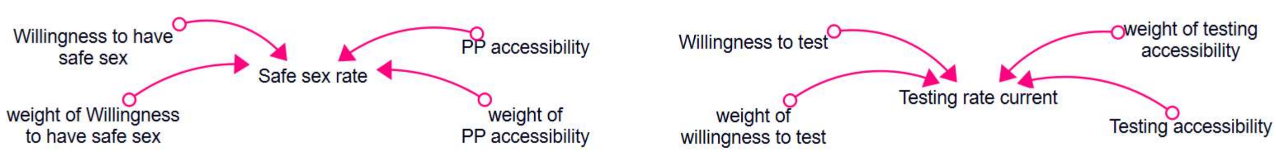


Figure 30 Weights of variables

Therefore, as it was described in Chapter 2, the model assumes that social behavior materials aspects (both accessibility weights are equal to 0.3) have lower weights than mental attitudes (both willingness weights are equal to 0.7).

Difficult Model Variables

It was challenging to build the part of the SD model that can correctly calculate infecting rate through sexual transmission. The risk of HIV transmission through sex acts is frequently estimated (Fox & Fidler, 2010). “There are challenges in producing accurate measures of risk because study participants often practice a variety of sex acts, and the timing of an individual’s seroconversion and subsequent transmission to a partner, the number of sex acts, and the potential HIV risk co-factors are rarely accurately known” (HIV transmission risk: a summary of the evidence, 2012). Combine this with the cultural stigma around sex in Russia, and there is no proper study that can give absolute accurate numbers. It means that the numbers might not be perfect in the model, but all behaviors and correlations are observed correctly.

Policies effectiveness

Nevertheless, in reality, there are factors that are hard to foresee, such as individual human decisions. The model assumes that 100% of the population that got SE will receive it properly and it will directly decrease their individual stigma to get tested down to zero. Another obstacle that can be faced is that not all 100% of the population will get an SE education since there are parts of Russia are geographically and economically dissimilar, so not all places will have enough resources to implement this policy. Therefore, to make it more realistic, in the model the effectiveness of SE is equal 80% and the share of total population that gets SE also 80%.

5. Model Validation

This chapter aims to check the validity of the built theoretical model – "not to prove that the model is valid, but to judge how valid it likely is" (Barlas, 1996). Validation testing helps not only to confirm that there are no errors in the model but also to analyze it on a deeper level and see its strong and weak points. No model can be completely verified or validated, there are always a colossal number of differences between the theoretical model and reality. "All models, mental or formal, are limited, simplified representations of the real world. They differ from reality in ways large and small, infinite in number" (Sterman, 2000). There is a wide range of model validation tests that were developed by SD modelers (e.g., Forrester 1973; Forrester and Senge 1980; Barlas 1989, 1990, 1996). Hence, for this thesis, several tests were chosen that are the most relevant to the developed model and are the most commonly used.

5.1. Direct Structure Test

Structure confirmation test. A structure confirmation test's goal is to compare the model's internal correlations and its equations with the relationships and laws that exist in the real system (Forrester & Senge, 1980). In this work the model's conceptual underpinnings are based on a thorough literature analysis on information security conducted during the model-building process.

Parameter confirmation test. The purpose of the parameter verification test is to determine whether each parameter (constant exogenous variable) corroborates with the known components of a "real" system (conceptual) and whether their values lie within plausible ranges (numerical) (Barlas, 1996).

The parameters of this model were regularly compared to the theoretical and numerical literature related to the topic, the sources could be found in the model documentation (see the appendix). However, not all variables' values were found in open available sources, some of them are just not calculated or discovered yet, which is why some of the variables were suggested based on existing literature and collected data.

Dimensional consistency test. The model has no equations errors or unit errors or recommendations from Stella Architect to change units. All units are dimensionally consistent.

The main units of the model's stocks and flows are people and people/year; probabilities, effects, fractions, and weights are dimensionless.

5.2. Structure Oriented Behavior Tests

Extreme conditions test. The test aims to confirm that model equations withstand challenging circumstances. The model responds plausibly to different extreme conditions, one of the variables that were put in extreme conditions is Death. The model had no errors and produced reasonable behavior (Figure 33). Run1 is a base run with no changes, Run2 - Death Rate increased about ten times (0.14), and Run3 – Death Rate decreased about 10 times (0.0014).

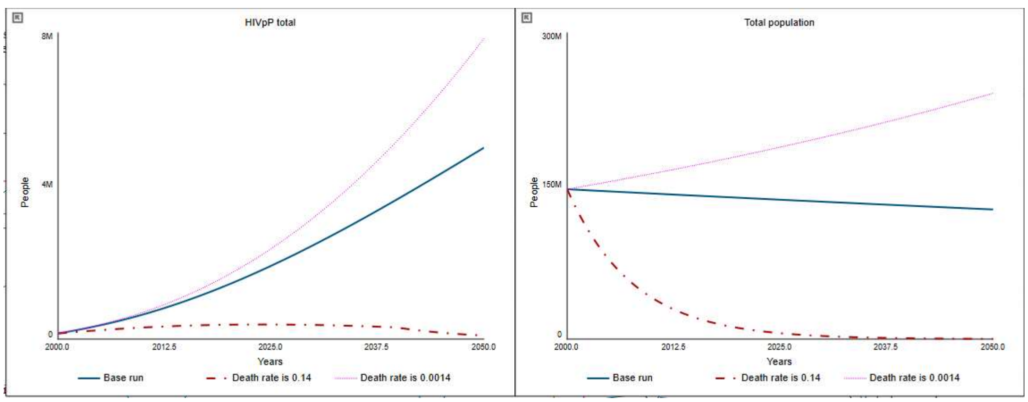


Figure 31 Extreme conditions test

Behavior sensitivity test. The behavior sensitivity test consists of determining those parameters to which the model is highly sensitive and asking if the real system would exhibit similar high sensitivity to the corresponding parameters (Aguiar, 2017). The parameters of the model were tested and demonstrated reasonable responses, examples of some parameters sensitivity tests are explained further.

There are three exogenous variables that were tested with 10 runs each with incremental distributions: New cases caused by other reasons (from 0 to 60000, the real value is 34000); Death Rate – Highly sensitive (from 0 to 0.1, the real value is 0.0142); Birth Rate – Slightly sensitive (from 0 to 0.1, the real value is 0.0113). All three variables showed normal sensitive response to the changes (Figures 32, 33, 34).

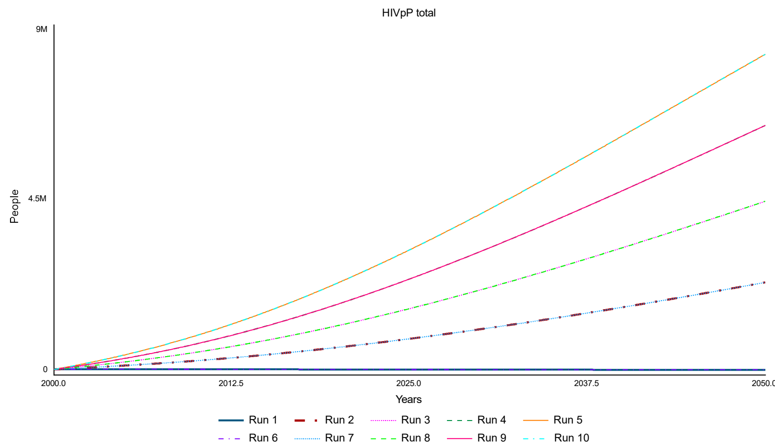


Figure 32 New cases caused by other reasons sensitivity test

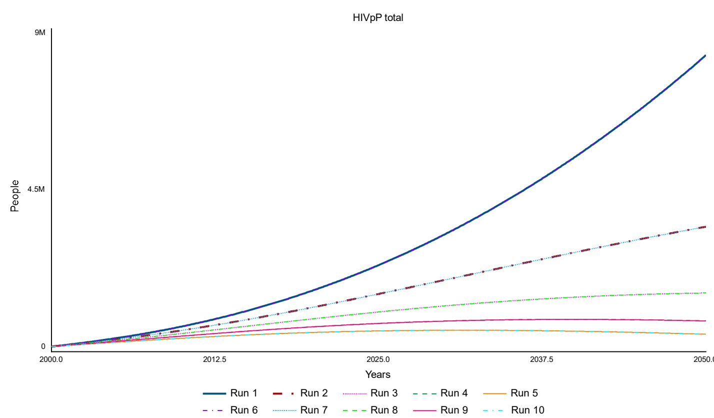


Figure 33 Death Rate sensitivity test

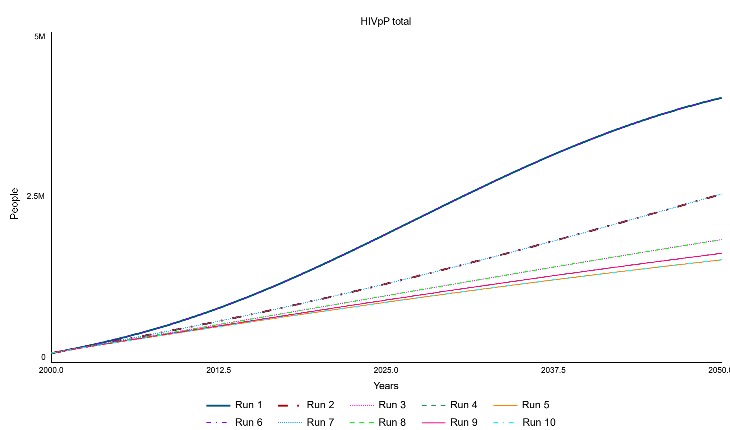


Figure 34 Birth Rate sensitivity test

The graph below illustrates the change in the total HIV-positive population with the Stigma level changing from 0 to 1, the model expressed a high sensitivity towards these corrections.

(Figure 35). These results prove the importance of Stigma and confirm the need to build the possible policies in order to change the stigma level.

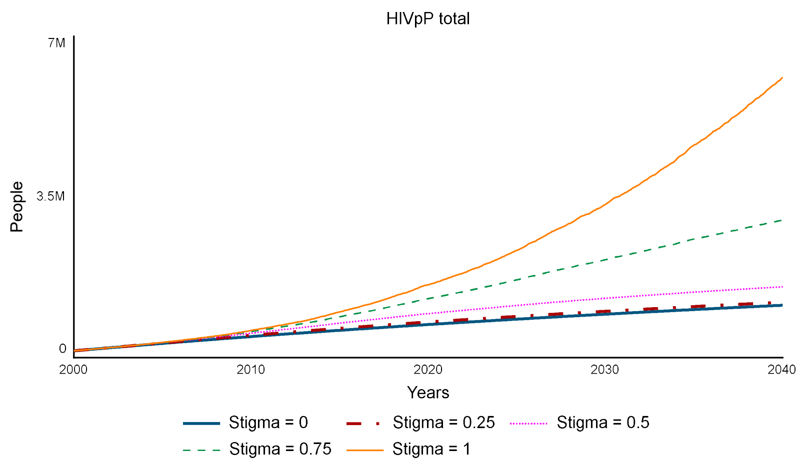


Figure 35 The stigma level sensitivity test

Integration method and DT error tests. The purpose of the integration error test is to determine whether model simulation results are sensitive to the choice of time step or numerical integration method used in the model settings (Sterman, 2000). For the integration method test the model was running three times with alternative integration methods. The results showed that the model is not sensitive to the choice of numerical integration method (Figure 36). The DT test is conducted by increasing the time step in 2, 4, and 12 times and running the model again each time (Figure 37). The result of this test was that the model is not sensitive to changes in DT.

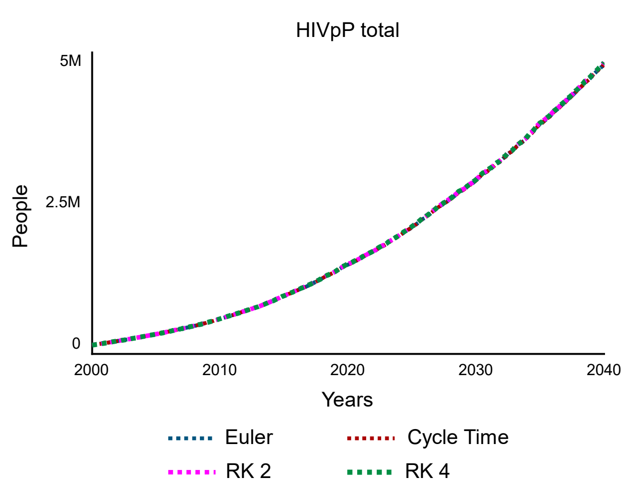


Figure 36 Change of integration method

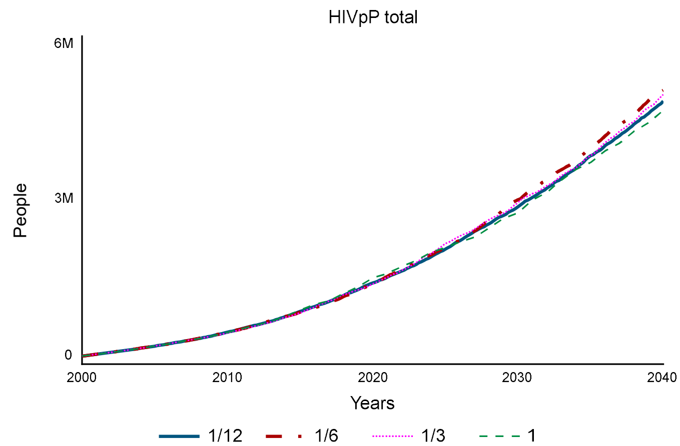


Figure 37 Change of time steps

5.3. Behavior Pattern Test

Behavior Reproduction Test. Behavior pattern tests are conducted to measure how accurately the model can reproduce the major behavior patterns exhibited by the real system (Aguiar, 2017). It is the last but one of the most important tests that will be conducted for the thesis model. All in all, this test compares the model's produced behavior to the behavior of the real system (reference mode), they do not always have to match perfectly, moreover, some models might not have any reference mode.

In the current thesis, the reference mode is the total number of HIV-positive people, in the model it is the variable "HIVpP total" (HIV-positive Population total). The bar below presents the comparison between them in a time frame from 2000 to 2021 (Figure 38).

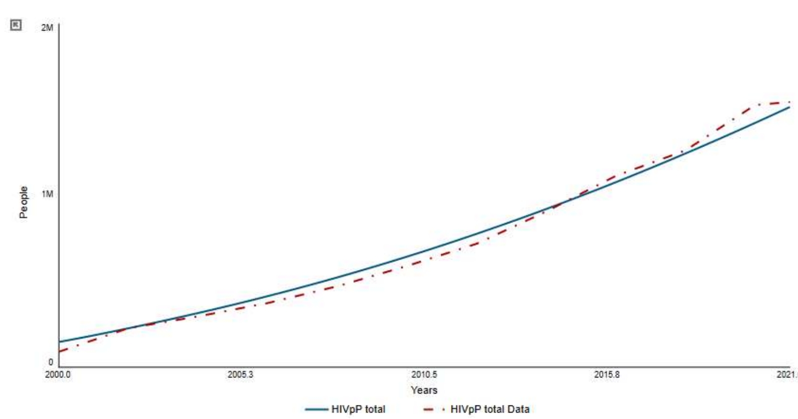


Figure 38 Behavior reproduction test

Another parameter that was compared is the number of a total population of Russia from 2000 to 2021 (Figure 39). The demographical situation in the country is stable for the last decades, and the model shows similar results.

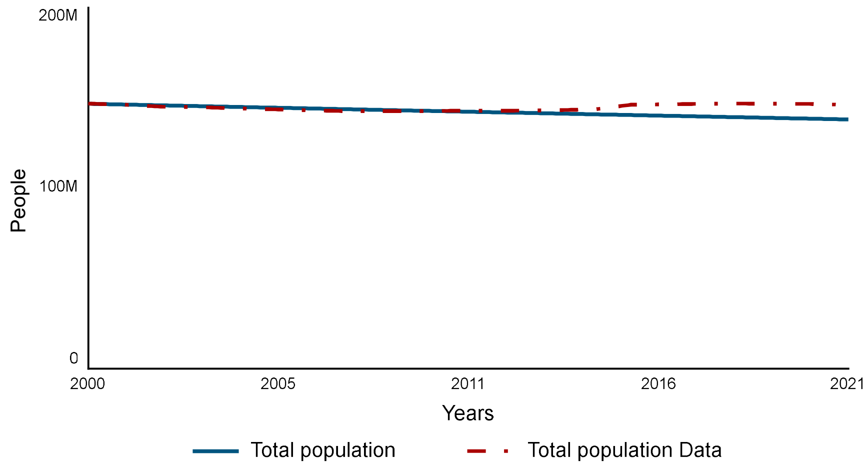


Figure 39 Total population of Russia

6. Scenario and Policy Analysis

This chapter describes the analysis of the model behavior under different scenarios and policy alternatives. The three policies suggested in this work are: Sex Education Policy, Condom Accessibility, and Testing Accessibility.

6.1. Base run

A base run is a simulation that should replicate the behavior pattern shown by data that is approximate to the historical one. In this scenario none of the suggested policies are activated and all external factors are the same as in an ordinary situation for the system. The base run for a period from 2000 to 2021 was presented earlier as a result of the behavior reproduction test (Figure 40). The resulted model simulation appears to reflect the observed data's behavioral trend.

Moreover, the base run from 2000 to 2050 shows a future scenario for the next 28 years, according to the prognosis the number of HIV-positive people will be increasing increasingly if everything remains the same (Figure 40). If in 2021 the average percentage of HIV-infected people is about 1%, then in 2050 it might reach almost 4%.

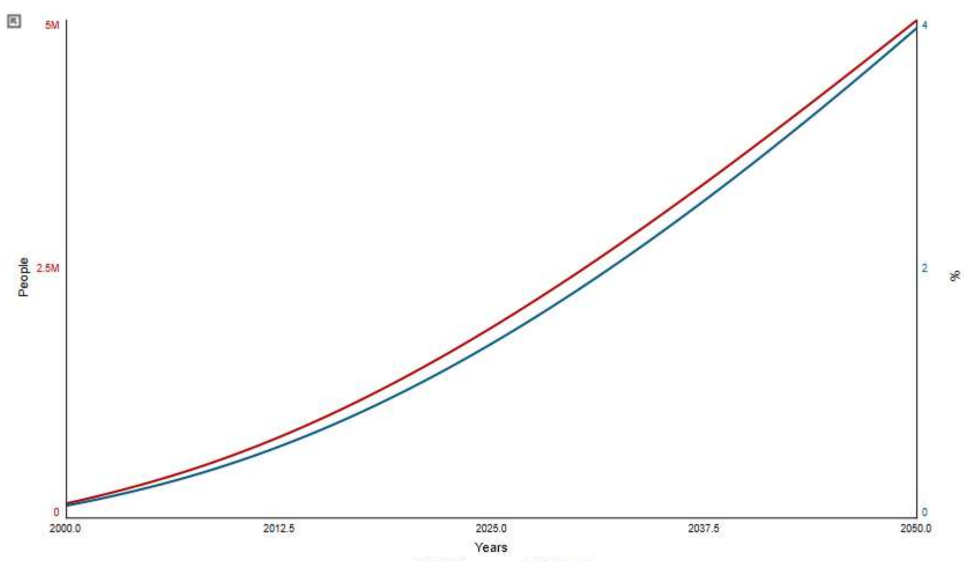


Figure 40 The total number of HIV-positive people from 2000 to 2050

Another parameter of the built model that is used as a key indicator in this chapter is "Infection rate sex contacts" which calculates the number of new HIV cases by sex contacts each year (Figure 41), the rate increases steadily with slow decrease of the growth speed.

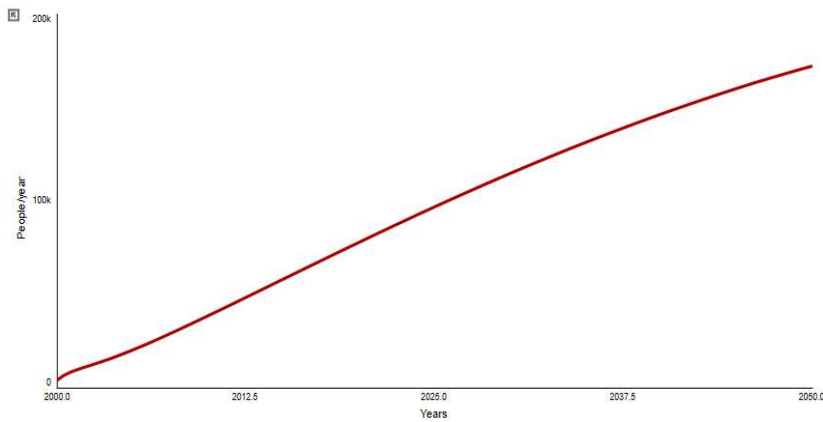


Figure 41 Infection rate by sex contacts base run

6.2. Sex Education Policy

The main policy that the model is oriented on is Sex Education Policy (SEP) which consists of two blocks: sex education classes in educational institutions and spreading sex education and HIV awareness through the mass media and news. Assuming that with the new policy population above 14 gets completed SE in an average of two years, in the best-case scenario the number of new cases will be cut to almost a tenth of what it is today (Figure 42), and the total number of HIV-positive people will stop its growth (Figure 43).

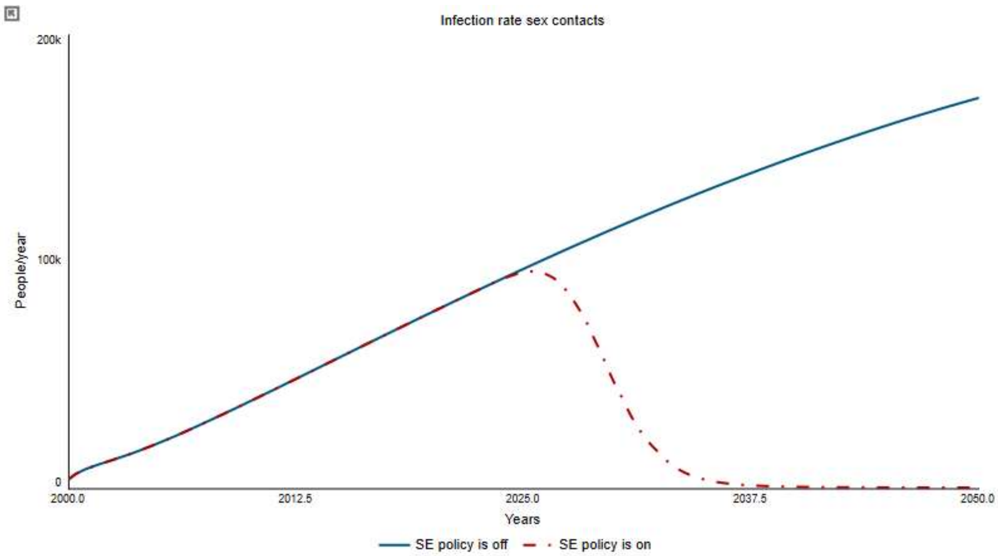


Figure 42 Infection rate by sex contacts with SEP

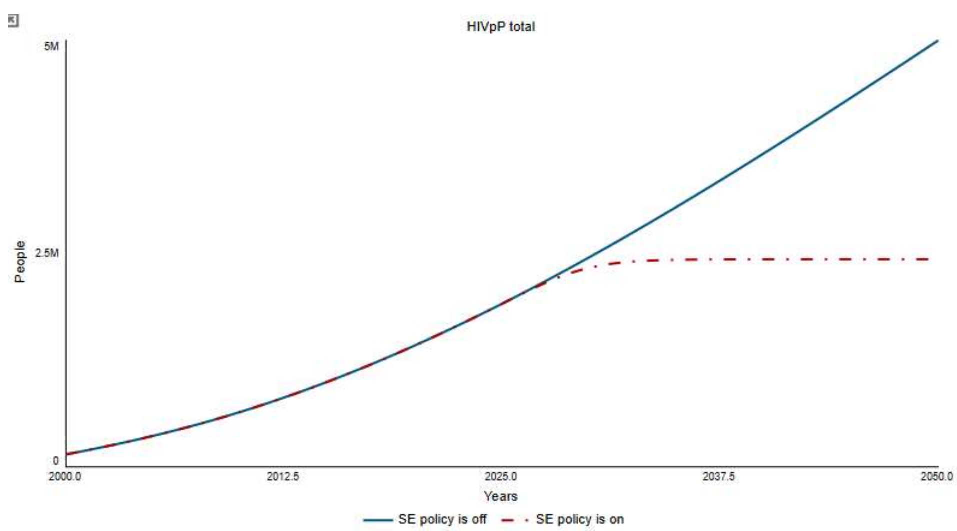


Figure 43 Total number of HIV positive people with SEP

As mentioned before, in the real life there are struggles that are hard to predict and be completely ready to the results, for instance individual human decisions. The model already has a decreased effectiveness of SE (80%) and a decreased share of population who gets SD (80%). However, there could be several barriers that hinder the effectiveness of this policy like deficient teaching or personal characteristics. That is why it is reasonable to simulate the model with a possible drawback that decreases the effectiveness of SE. The results are presented below (Figure 44).

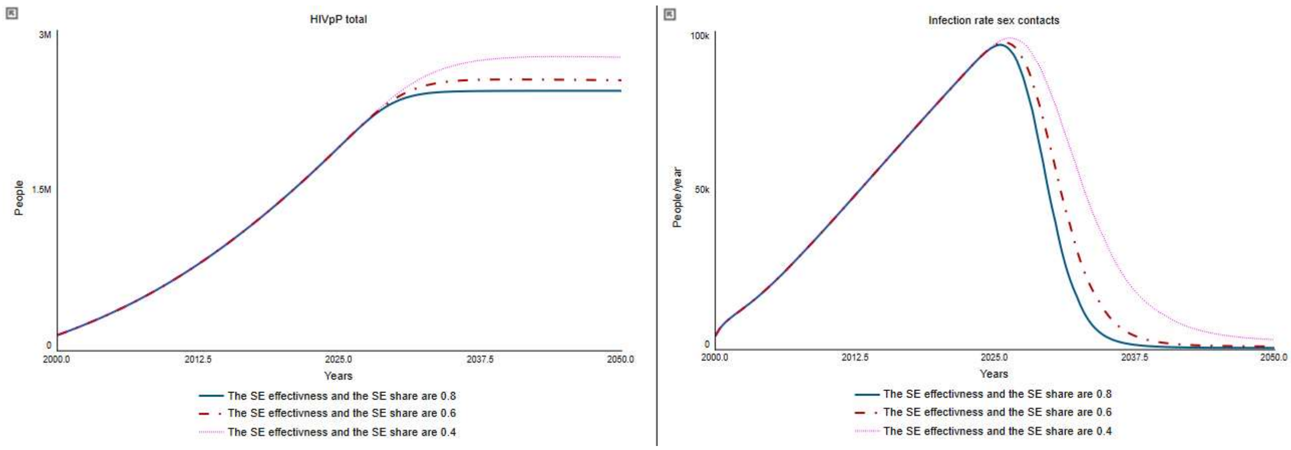


Figure 44 SEP is on with different scenarios

6.3. Condom Accessibility and Testing Accessibility Policies

The other two policies are Condom Accessibility Policy (CAP) and Testing Accessibility Policy (TAP). Even if the whole population has willingness to get tested it will not happen if it is not available for everyone. For now, HIV tests in Russia are not free (300–1,000 rubles or about $4–$13), which for many means inaccessible, especially if testing is not forced by other reasons (Sarkysyan, 2020). There is the same problem with condom use – for a significant portion of the population, especially young people and marginalized groups, use of condoms is an expensive habit. The model assumes that accessibility of tests and condoms will positively influence a person's decision to use a condom and to get tested on regular basis. The graphs below illustrate the results of switching on accessibility policies in the model (Figures 45 and 46). Hence, again, there are many factors that are not included in the model that can be obstacles to reach 100% effectivity of the policies, therefore it is reasonable to see the model run with decreased effectivities.

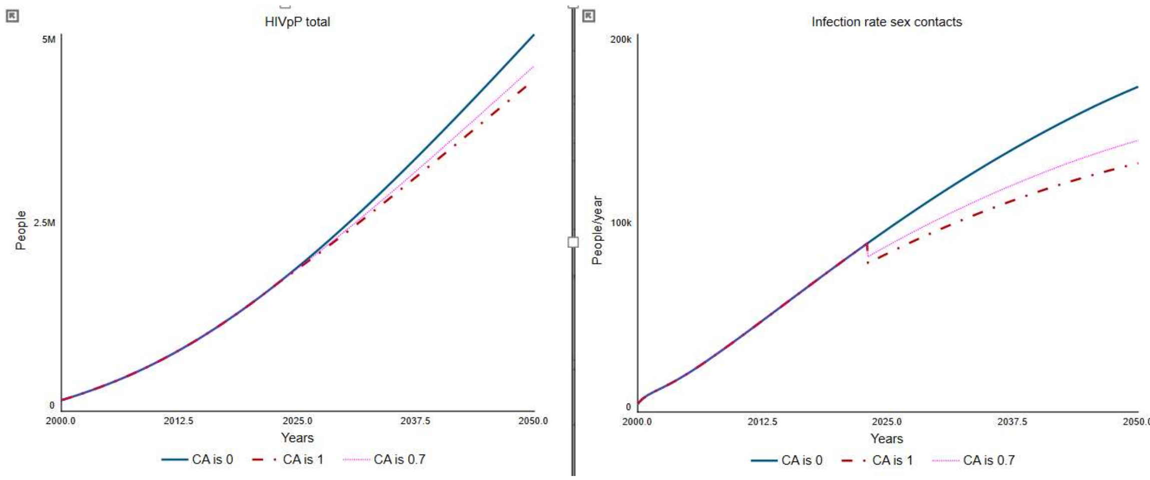


Figure 45 CAP effect on the model behavior

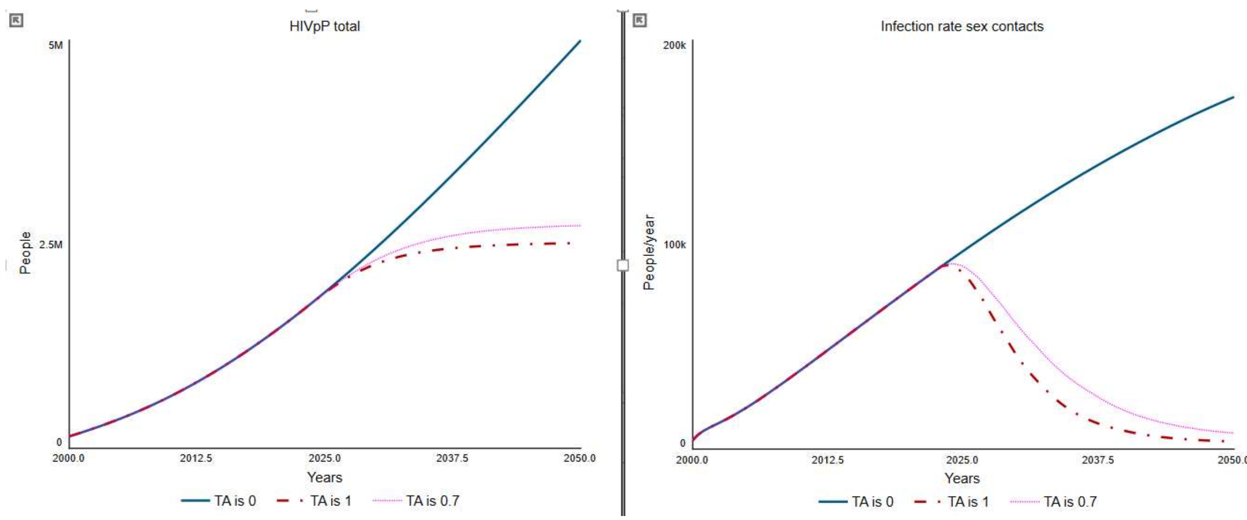


Figure 46 CAP effect on the model behavior

Based on the results of these runs it is shown that even without absolute effectivity of the policies, the speed of epidemic is slowing down. It also indicates that accessibility of testing has bigger impact than condom accessibility, the reason might be that in the model willingness to get tested involved in more loops (B1, B2, R2) than willingness to have safe sex (B2, R2).

6.4. Comparison Policies

The diagram below illustrates the map of processes that are activated by the developed policies (Figure 47).

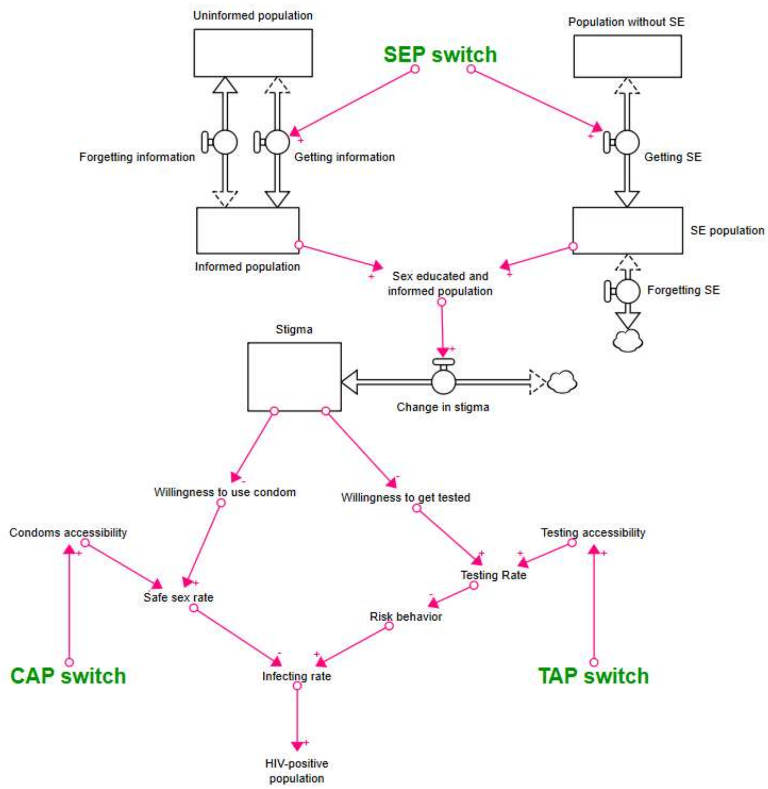


Figure 47 Map of the policies in the model

Based on the model simulation results, it can be concluded that the policies are working successfully, not interrupting each other, and gives the best results when all three of the policies are on (Figure 48).

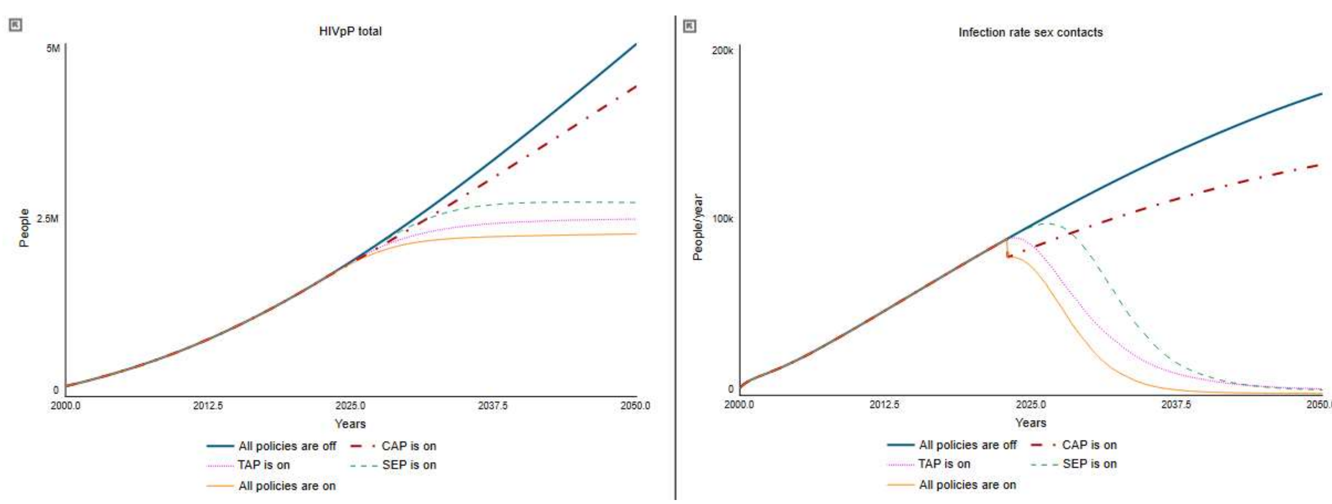


Figure 48 Comparison of the policies

Though the results might look too optimistic, with limitations in real life the positive results might happen over longer period of time. Hence, education and information are processes that include information delays. An information delay is a delay that represents the gradual adjustment of information, perceptions, or beliefs, or a gradually delayed impact of some variable on a flow or auxiliary variable used to model non-conserved variables (Ford, 2019). Things like HIV stigma and education of the population take some time to be changed. Accessibility policies in real life include other material and informational delays, but they are not included in the model boundaries, such as supply chain delays.

All in all, it can be concluded that SEP is the most effective solution in both short and long time terms. The best option is to combine all three policies (Figure 48), however, some of the policies might be easier to implement depending on money and time spends.

7. Conclusion

This study presented a system dynamics approach to understand the HIV spreading mechanisms in Russia. The aim of this research was to investigate the dynamic behavior of the HIV transmission mechanisms in Russia, delineate the causal connections between the system's internal parts, and pinpoint relevant policy solutions. Thus, the objectives were focused on determining the key elements of the system and analyzing their interactions, in order to create potential policy recommendations to aid in reducing the rate of HIV transmission in Russia. The summary of the thesis answers on the research questions are presented below.

7.1. Answer to Research Questions

Research Question 1.1: What are the key feedback mechanisms responsible for the constant growth of HIV spreading in Russia? Based on literature and data research the SD model was built and analyzed (chapters 3, 4, 5). The system of HIV spreading in Russia has several feedback connections, the most significant connections interact with HIV infection rate and HIV stigma. The figure below is from Chapter 3, it illustrates four major feedback loops that drives the system (Figure 49).

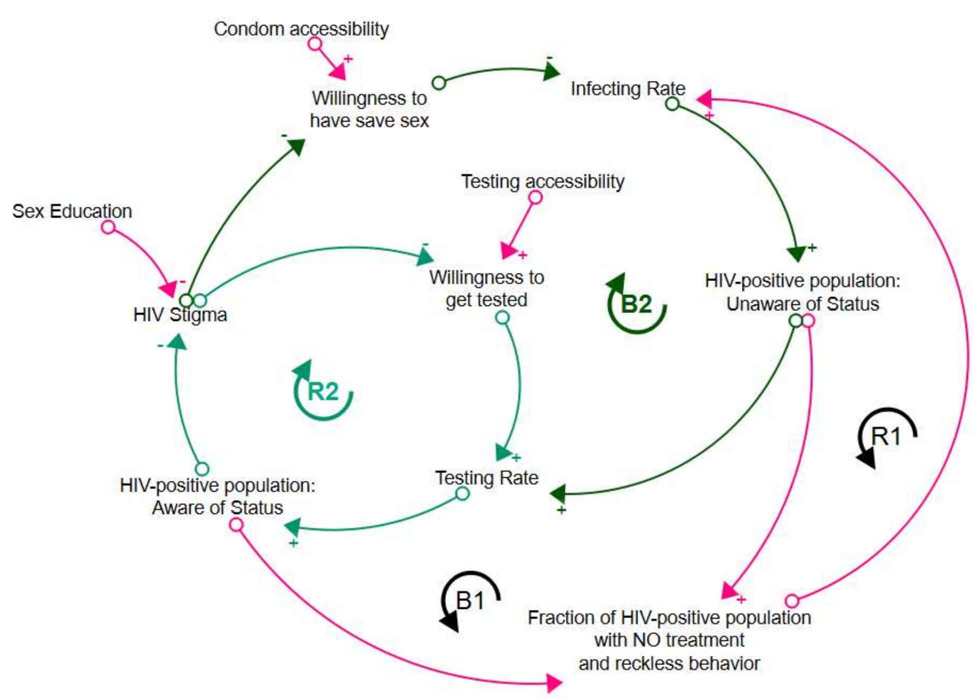


Figure 49 CLD of the model with its policies

Loops R1 and B1 are classic loops that are standard parts of the most systems of spreading contagious diseases. The R1 loop amplifies HIV infection and raises the annual number of new cases, while the B1 loop is trying to maintain a balance – a bigger infecting number leads to a smaller infecting number and vice versa. The R1 loop circulates in an isolated chain of people getting infected, not being aware of their status nor receiving a treatment, and infecting other people. The B1 loop has further steps in it on account of the HIV testing system, that increases the number of aware infected population and decreases the number of unaware infected population.

The next two loops interact with the target of the further suggested policies – HIV stigma. The R2 is a loop that relies on a society's cohesiveness mechanisms, so the more HIV-positive people know their status, the more relatives and friends are aware of it, the more conversations and research about HIV, that leads to a decrease of HIV stigma, and to a decrease of the infecting rate consequently. Therefore, a decrease of testing will cause to the opposite result – growth of the annual number of new HIV cases. The B2 is extended by links between the prevalence of HIV stigma and people's willingness to practice safe sex. The smaller the stigma, the bigger HIV awareness and thus more people want to follow guidelines and have safe sex.

Research Question 1.2: Which mechanisms or key factors contribute more to the spread of HIV in Russia? Based on the above the most important factors are those that influence safe sex and testing rate. Therefore, after the study analysis the prioritized factors that were determined are sex education and information, condom accessibility, and testing accessibility. These parameters were highlighted as the main mechanisms that triggers adjustments in HIV stigma, that has major impacts on the key drivers of the constructed model - the safe sex rate and the testing rate, which both go on to impact the infecting rate and the number of HIV-positive population.

Research Question 2.1: What are the potential policy alternatives that can help reduce or slow down HIV spreading? Based on the answer to the previous research questions the policies that are suggested to decrease the speed of HIV spreading are: Introduction and implementation of sex education programs; Increase the coverage of relevant HIV information in the news and on social media; Free and anonymous condom access; Free and anonymous testing access. These policies are aimed to target the established key factors of HIV epidemic in Russia. The figure below is from Chapter 6, and it presents a simplified map of the policies impacts in the model (Figure 50).

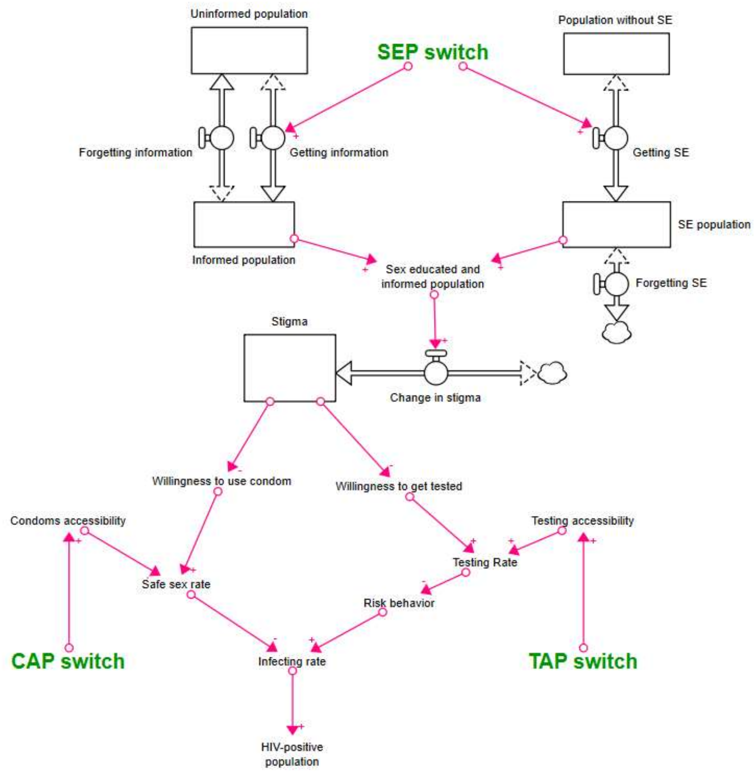


Figure 50 Map of the policies in the model

Research Question 2.2: Which insights can be derived from possible future scenarios and policy simulations? The best-case (if all the policies are implemented successfully) and worst-case scenarios (if nothing changes and no policies are introduced) are illustrated in the graphs below (Figure 51). In between these polar results, various behaviors can result depending on how many struggles the implementation will face which will decrease effectivity of the policies (more in Chapter 6).

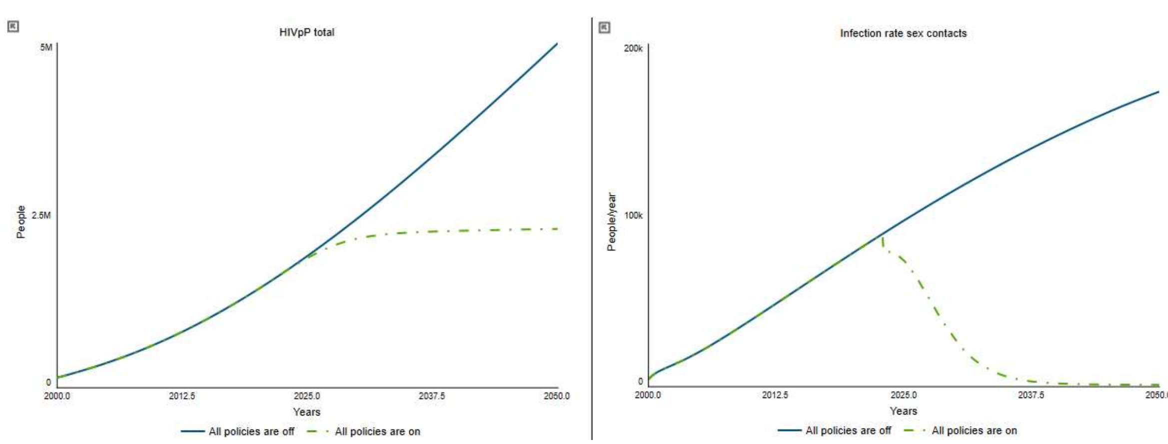


Figure 51 Best case scenario – with all policies on, worst case scenario – all policies are off

Research Question 2.3: Which further challenges and limitations should be taken into consideration when it comes to policy implementation? There is a wide range of challenges that could appear during the policy's implementation. Chapter 6 considers different potential obstacles, such as that a human decision cannot be fully predicted, for example, an educated and informed person might still not follow preventative HIV guidelines. The sex education programs in some places could have worse qualities. Condom and testing accessibility could face struggles with financing or supply chains.

7.2. Limitations and Further Work

As was mentioned before, none of the SD models are perfect or are an exact representation of the real-world system. Hence, the developed model has its boundaries and does not include all the components of the HIV-spreading system. Moreover, not all variables present completely accurate numbers, some of them are assumed or interpreted based on the reviewed literature and logical thinking. One of the biggest unknown components in the model are intangible variables consisting of human behavior and human decision factors, and this study relies on some level of predictability of it, while in real life it is hard to predict population choices and behavior with an absolute accuracy.

For future research, it would be helpful to expand the stigma section of the model. Thus, in this study the stigma level is presented as one abstract variable with values from 0 to 1, it has a more complicated structure and can be built differently depending on the desired level of difficulty. It seems that a more detailed SD analysis of HIV stigma, its causes, and effects, will give more answers and suggestions for more effective and concrete policies. In addition to this, the HIV stigma itself has a complex system with a range of feedback relationships.

Despite the model's limitations, this study sheds some light on understanding the HIV epidemic in Russia, which could be further developed to provide a tool that could be used to better inform decision makers to design more robust policies against HIV spreading in Russia in a shorter time and with fewest obstacles.

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Appendix: model documentation

Total	Count	Including Array Elements
Variables	114	114
Sectors	12	
Stocks	13	13
Flows	27	27
Converters	74	74
Constants	41	41
Equations	60	60
Graphicals	7	7

	Equation	Units	Documentation
HIVnP_above_50(t)	HIVnP_above_50(t - dt) + (Aging - HIVnP_Dying_3) * dt	People	The stock of population that does not have HIV and above 50 years old.
HIVnP_from_16_to_50(t)	HIVnP_from_16_to_50(t - dt) + (Growing - Aging - Infecting - HIVnP_Dying_2) * dt	People	The stock of population that does not have HIV between 16 and 50 years old.
HIVnP_under_16(t)	HIVnP_under_16(t - dt) + (Birthing - Growing - HIVnP_Dying_1) * dt	People	The stock of population that does not have HIV and have not reached 16 years old.
"HIVpP_Aware,_with_no_treatment"(t)	"HIVpP_Aware,_with_no_treatment"(t - dt) + (Testing - HIVpP_A_dying - Getting_Treatment) * dt	People	An approximate number of the HIV-positive population that are aware of their status but with no treatment in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
HIVpP_in_treatment(t)	HIVpP_in_treatment(t - dt) + (Getting_Treatment - HIVpP_T_dying - Suppressing) * dt	People	An approximate number of the HIV-positive population that are aware of their status and on treatment in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.

HIVpP_Unaware_of_status(t)	HIVpP_Unaware_of_status(t - dt) + (Infecting - Testing - HIVpP_U_dying) * dt	People	An approximate number of the HIV-positive population that are not aware of their status in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
HIVpP_virally_suppressed(t)	HIVpP_virally_suppressed(t - dt) + (Suppressing - HIVpP_T_dying_1) * dt	People	An approximate number of the HIV-positive population that are aware of their status, on treatment, and virally suppressed in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
Informed_population(t)	Informed_population(t - dt) + (Getting_information - Dying_4 - Forgetting_information) * dt	People	The stock of population who have relevant and recent information about HIV.
Kids_before_14(t)	Kids_before_14(t - dt) + (Birthing_1 - Growing_1 - Dying_5) * dt	People	The stock of population without school sex education above 14 years old.
Population_without_SE(t)	Population_without_SE(t - dt) + (Growing_1 - Dying_1 - Getting_SE) * dt	People	The stock of population without sex education.
SE_population(t)	SE_population(t - dt) + (Getting_SE - Dying_2 - Forgetting_SE) * dt	People	The stock of population who got school sex education at school, college, univercity, or work.
Stigma(t)	Stigma(t - dt) + (- Change_in_stigma) * dt	Dimensionless	The value of The stigma stock indicates the general level of social HIV stigma. In this model Stigma is a soft variable, its value is calculated based on the population's HIV awareness without a specific strict equation.
Uninformed_population(t)	Uninformed_population(t - dt) + (Forgetting_information + Growing_2 - Dying_3 - Getting_information) * dt	People	The stock of population who do not have relevant and recent information about HIV.
Aging	HIVnP_from_16_to_50/Aging_time	People/year	The rate at which people move from "HIVnP from 16 to 50" stock to "HIVnP under 16" by growing.
Birthing	Birth_Rate*Total_population	People/year	The rate at which people are adding to the "HIVnP under 16 " stock.

Birthing_1	Birthing	People /year	The rate at which people are adding to the "Kids before 14" stock.
Change_in_stigma	IF TIME < 2023 THEN 0 ELSE (Indicated_stigma_1+Stigma-Indicated_stigma)/Time_to_change_stigma*SE_policy_switch	people /people/year	The rate at which the "Stigma level" stock is changing by losing its dmnl units.
Dying_1	Death_rate*Population_without_SE	People /year	The rate at which people are leaving the "Population without SE" stock by dying.
Dying_2	Death_rate*SE_population	People /year	The rate at which people are leaving the "SE population" stock by dying.
Dying_3	Death_rate*Uninformed_population	People /year	The rate at which people are leaving the "Uninformed population" stock by dying.
Dying_4	Death_rate*Informed_population	People /year	The rate at which people are leaving the "Informed population" stock by dying.
Dying_5	Death_rate*Kids_before_14	People /year	The rate at which people are leaving the "Kids before 14" stock by dying.
Forgetting_information	Informed_population/Forgetting_information_time	People /year	The rate at which people move from "Informed population" stock to "Uninformed population" stock by forgetting information.
Forgetting_SE	SE_population/Forgetting_SE_time	People /year	The rate at which people are leaving the "SE population" stock by forgetting SE knowledge.
Getting_information	IF TIME < 2023 THEN 0 ELSE Uninformed_population*SE_policy_switch/Time_to_get_information	People /year	The rate at which people move from "Uninformed population" stock to "Informed population" stock by getting informed.
Getting_SE	IF TIME < 2023 THEN 0 ELSE Share_of_population_that_gets_SE*Population_without_SE*SE_policy_switch/Getting_SE_time	People /year	The rate at which people move from "Population without SE" stock to "SE population" stock by getting SE education.
Getting_Treatment	Percentage_on_treatment*"HIVpP_Aware,_with_no_treatment"	People /Years	The rate at which people move from "HIVpP Aware, with no treatment" stock to "HIVpP on treatment' by starting treatment.
Growing	HIVnP_under_16/Growing_time	People /year	The rate at which people move from "HIVnP under 16" stock to "HIVnP from 16 to 50" by growing.
Growing_1	Kids_before_14/Growing_time_1	People /year	The rate at which people move from "Kids before 14" stock to "Population without SE" by growing.

Growing_2	Growing_1	People /year	The rate at which people are adding to the "Uninformed population" stock by growing.
HIVnP_Dying _1	Death_rate*HIVnP_under_16	People /year	The rate at which people are leaving the "HIVnP under 16 yo" stock by dying.
HIVnP_Dying _2	Death_rate*HIVnP_from_16_t o_50	People /year	The rate at which people are leaving the "HIVnP from 16 to 50" stock by dying.
HIVnP_Dying _3	HIVnP_above_50*Death_rate	People /year	The rate at which people are leaving the "HIVnP above 50 yo" stock by dying.
HIVpP_A_dyi ng	Death_rate*"HIVpP_Aware,_w ith_no_treatment"	People /year	The rate at which people are leaving the "HIVpP Aware, with no treatment" stock by dying.
HIVpP_T_dyi ng	Death_rate*HIVpP_in_treatme nt	People /Years	The rate at which people are leaving the "HIVpP on treatment" stock by dying.
HIVpP_T_dyi ng_1	Death_rate*HIVpP_virally_sup pressed	People /Years	The rate at which people are leaving the "HIVpP virally suppressed" stock by dying.
HIVpP_U_dyi ng	Death_rate*HIVpP_Unaware_o f_status	People /year	The rate at which people are leaving the "HIVpP Unaware of status" stock by dying.
Infecting	Infection_rate_sex_contacts+N ew_cases_caused_by_other_rea sons	People /year	The rate at which people move from "HIVnP from 16 to 50" stock to "HIVpP Unaware of status' by infecting.
Suppressing	HIVpP_in_treatment*Suppressi ng_speed	People /Years	The rate at which people move from "HIVpP on treatment" stock to "HIVpP virally suppressed' by becoming virally suppressed.
Testing	HIVpP_Unaware_of_status*Te sting_rate_current	People /year	The rate at which people move from "HIVpP Unaware of status" stock to "HIVpP Aware, with no treatment' by getting tested.
"%_of_Unawa re_HIVpP"	HIVpP_Unaware_of_status/HI VpP_total	dmnl	The share/fraction of the HIV-positive population who are not aware of their status of the total HIV-positive population.
Aging_time	34	Years	Time to reach 50 years old.
Birth_Rate	0.0113	dmnl/y ear	The average ratio of the population growth each year. according to The Federal State Statistics Service.
Condom_acce ssibility	IF TIME < 2023 THEN Condom_accessibility_old_poli cy ELSE IF Condom_accessibility_policy_s witch = 1 THEN Condom_accessibility_new_pol icy ELSE Condom_accessibility_old_poli cy	dmnl	The current ratio of accessibility of free condoms starts in 2023.

Condom_accessibility_new_policy	1	dmnl	This variable represents the desired percentage of how many people can get condoms for free and anonymously.
Condom_accessibility_old_policy	0	dmnl	The old and current ratio of accessibility of free condoms.
Condom_accessibility_policy_switch	0	dmnl	A switch to activate and deactivate the Condom accessibility policy.
Contact_Rate	40	People/People/year	This variable represents the number of sex acts of one person with another person per year. There are no certain numbers that were founded to be used, therefore the number is assumed approximately.
Death_rate	0.0142	dmnl/year	The average ratio of the population decay each year. according to The Federal State Statistics Service.
Desired_stigma	0	dmnl	This variable represents the desired level of stigma among the total population.
Effect_on_stigma_SEIP	GRAPH(Sex_uneducated_uninformed_population) Points: (0.000, 0.000), (0.100, 0.0288159964689), (0.200, 0.0650838099109), (0.300, 0.110730480269), (0.400, 0.168181380035), (0.500, 0.240489083051), (0.600, 0.331495558785), (0.700, 0.446036310047), (0.800, 0.590197300723), (0.900, 0.771638325019), (1.000, 1.000)	dmnl	The assumed effect of the current informed sex educated population on change in stigma. It is expected that a bigger number of the uneducated uninformed population cause an increase in stigma. The effect maximum is 1 and the minimum is 0.
Effect_on_stigma_UHIVpP	GRAPH("%_of_Unaware_HIVpP") Points: (0.000, 0.000), (0.100, 0.0297279181464), (0.200, 0.0669568653463), (0.300, 0.113579521625), (0.400, 0.171966133171), (0.500, 0.245085013132), (0.600, 0.33665344749), (0.700, 0.451326677923), (0.800, 0.594934569333), (0.900, 0.774777993969), (1.000, 1.000)	Dimensionless	The assumed effect of the unaware HIV-positive population on change in stigma. It is expected that a bigger number of the unaware HIV-positive population causes an increase in stigma. The effect maximum is 1 and the minimum is 0.

Effectiveness_of_SE	1	Dimensionless	
Forgetting_information_time	1	Years	The time needed to forget information from the news and social media. Or for the information to get irrelevant, not fresh. The value is assumed.
Forgetting_SE_time	30	Years	The time needed to forget information from Sex education. Or for the information to get irrelevant, not fresh. The value is assumed.
Fraction_of_informed_population	Informed_population/(Informed_population+Uninformed_population)*Effectiveness_of_SE	dmnl	The share/fraction of the "Informed population" of the total number (the sum of "Informed population" and "Uniformed population").
Fraction_of_informed_population_weight	0.3	dmnl	The effect of the Fraction of the informed population on the computation reflects its importance in the Current not stigmatized population. The number is assumed.
Fraction_of_SE_population	SE_population/(SE_population+Population_without_SE)*Effectiveness_of_SE	dmnl	The share/fraction of "SE population" of the total number (the sum of "Population without SD" and "SE population").
Fraction_of_SE_population_weight	0.7	dmnl	The effect of the Fraction of SE population on the computation reflects its importance in the Current not stigmatized population. The number is assumed.
Fraction_of_Susceptible_Population	Susceptible_Population/Total_population	Dimensionless	The share/fraction of "Susceptible Population" of the total population.
Gap_between_actual_and_desired_stigma	(Stigma-Desired_stigma)	dmnl	This variable calculates the difference between actual the Stigma level and the Desired stigma level. In the best case scenario the gap between them should be 0.
Getting_SE_time	2	Years	Time each person need to get SE. The value is assumed.
Growing_time	16	Years	Time to reach 16 years old.
Growing_time_1	14	Years	The time needed to reach 14. The model assumes that kids are not getting sex education until then.
HIVnP_above_50_yo_in_2000	52062455	People	An approximate number of HIV-negative population above 50 in 2000. Calculated based on data from The Ministry of Health of the Russian Federation and The Federal Scientific and Methodological Center for the Prevention and Control of AIDS.

HIVnP_from_16_to_50_in_2000	68674777	People	An approximate number of HIV-negative population between 16 and 50 y.o. in 2000. Calculated based on data from The Ministry of Health of the Russian Federation and The Federal Scientific and Methodological Center for the Prevention and Control of AIDS.
HIVnP_total	HIVnP_above_50+HIVnP_from_16_to_50+HIVnP_under_16	People	The total number of uninfected HIV-negative population.
HIVnP_under_16_yo_in_2000	25920905	People	An approximate number of HIV-negative population under 16 y.o. in 2000. Calculated based on data from The Ministry of Health of the Russian Federation and The Federal Scientific and Methodological Center for the Prevention and Control of AIDS.
HIVpP_%	HIVpP_total/Total_population*100	%	
HIVpP_Aware_of_status_in_2000	72745	People	An approximate number of the HIV-positive population that are aware of their status in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
HIVpP_contagious	HIVpP_Unaware_of_status+"HIVpP_Aware,_with_no_treatment"+HIVpP_in_treatment	People	Total number of HIV-positive population that are not virally suppressed.
HIVpP_in_2000_total	90547	People	The total number of HIV-positive population in 2000 according to The Ministry of Health of the Russian Federation.
HIVpP_on_treatment_in_2000	32735	People	An approximate number of the HIV-positive population that are aware of their status and on treatment in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
HIVpP_total	HIVpP_virally_suppressed+HIVpP_contagious	People	The total number of HIV-positive population.
HIVpP_total_Data	GRAPH(TIME) Points: (2000.00, 89808.0), (2002.00, 227502.0), (2004.00, 296045.0), (2006.00, 373718.0), (2008.00, 471676.0), (2010.00, 589581.0), (2012.00, 719445.0), (2014.00,	People	The historical data of the total HIV-positive population in Russia from 2000 to 2022 according to The Ministry of Health of the Russian Federation.

	907607.0), (2016.00, 1114815.0), (2018.00, 1263321.0), (2020.00, 1528020.0), (2022.00, 1562570.0), (2024.00, 0.0), (2026.00, 0.0), (2028.00, 0.0), (2030.00, 0.0), (2032.00, 0.0), (2034.00, 0.0), (2036.00, 0.0), (2038.00, 0.0), (2040.00, 0.0)		
HIVpP_Unaware_of_status_in_2000	17064	People	An approximate number of the HIV-positive population that are not aware of their status in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
HIVpP_virally_suppressed_in_2000	24551	People	An approximate number of the HIV-positive population that are aware of their status, on treatment, and virally suppressed in 2000. Calculated based on data from The Ministry of Health of the Russian Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
Indicated_stigma	Normal_stigma*Effect_on_stigma_SEIP	dmnl	The Indicated stigma is given by the normal stigma level multiplied by the total effect of the sec uneducated uninformed population on the stigma.
Indicated_stigma_1	Normal_stigma*Effect_on_stigma_UHIVpP	dmnl	The Indicated stigma 1 is given by the normal stigma level multiplied by the total Effect of the unaware HIV-positive population on the stigma.
Infection_rate_sex_contacts	IR_overage*HIVpP_contagious*Fraction_of_Susceptible_Population*Risk_behavior	People/year	The rate of infections per year caused by sexual contact. The value is based on infecting rate overage, susceptible population, contagious population, and its risk behavior.
IR_overage	IR_safe_sex+IR_unsafe_sex/2	people/people/year	This variable calculates the overage of Infecting Rate between both protected and unprotected types of sex.
IR_safe_sex	Contact_Rate*TR_Safe_sex	People/people/year	This variable calculates the probability of a new HIV infection during sex with a condom per one person per year.
IR_unsafe_sex	TR_Unsafe_sex*Contact_Rate	People/people/year	This variable calculates the probability of a new HIV infection during sex without a condom per one person per year.
New_cases_caused_by_other_reasons	34000	People/year	Income of new HIV cases that are caused by other reasons (not sex contacts). The approximate average number according to The Ministry of Health of the Russian

			Federation; The Federal Scientific, Methodological Center for the Prevention and Control of AIDS; The Federal State Statistics Service.
Normal_stigma	0.9	dmnl	The normal operating value of stigma level in Russia.
Percentage_on_treatment	0.45	dmnl/year	The average value of the percentage of HIV-positive people who gets their treatment over the last years.
Reduction_in_risk_with_condom_use	0.3	Dimensionless	This variable represents a chance of getting HIV infection while using a condom. According to "The biology of HIV transmission Estimated HIV risk per exposure" (Roger Pebody, 2020) Condom use during vaginal sex cause 71% reduction in risk and 70% during anal sex.
Risk_behavior	GRAPH("%_of_Unaware_HIVpP") Points: (0.000, 0.0000), (0.100, 0.167915455835), (0.200, 0.280472551921), (0.300, 0.35592182975), (0.400, 0.406496993138), (0.500, 0.440398538989), (0.600, 0.463123424764), (0.700, 0.478356371243), (0.800, 0.488567320628), (0.900, 0.49541192469), (1.000, 0.5000)	dmnl	The assumed effect of the percentage of the HIV-positive population not aware of their status on the probability of the risk behavior - sex without condoms. It is expected that a bigger number of the first variable cause an increase in the second one. The effect maximum is 1 and the minimum is 0.
Safe_sex_rate_overage	weight_of_Willingness_to_have_safe_sex*Willingness_to_have_safe_sex+Condom_accessibility*weight_of_Condom_accessibility	Dimensionless	The ratio of sexual acts with condoms. The value is calculated as the overage number of the Willingness to have safe sex and the Condom accessibility considering their weights.
SE_policy_switch	0	dmnl	A switch to activate and deactivate the SE policy.
Sex_educated_informed_population	Fraction_of_SE_population*Fraction_of_SE_population_weight+Fraction_of_informed_population_weight*Fraction_of_informed_population	dmnl	Value of how many percentages of the total population are NOT stigmatized (meaning population who are not informed or/and sex educated). Calculated as the average number of the SE population and the informed population considering their weights.
Sex_uneducated_uninformed_population	1-Sex_educated_informed_population	dmnl	Value of how many percentages of the total population are stigmatized (meaning population who are not informed or/and sex educated).

Share_of_population_that_gets_SE	1	dmnl	This variable represents the desired percentage of how many people are getting sex education each year,
Suppressing_speed	0.75	dmnl/year	The value presents the speed of HIV-positive people in treatment becoming virally suppressed.
Susceptible_Population	HIVnP_from_16_to_50	People	The Susceptible Population is the population that is in position more likely get infected. The population between 16 and 50 is assumed as the most sexually active group based on age. There are no certain numbers that were founded to be used.
Testing_accessibility	IF TIME < 2023 THEN Testing_accessibility_old_policy ELSE IF Testing_accessibility_policy_switch = 1 THEN Testing_accessibility_new_policy ELSE Testing_accessibility_old_policy	dmnl/year	The current ratio of accessibility of free testing starts in 2023.
Testing_accessibility_new_policy	1	dmnl/year	This variable represents the desired percentage of how many people can get tested for free for free and anonymously.
Testing_accessibility_old_policy	0.01	dmnl/year	The old and current ratio of testing accessibility before 2023.
Testing_accessibility_policy_switch	0	dmnl	A switch to activate and deactivate the Testing accessibility policy.
Testing_rate_current	Testing_accessibility*weight_of_testing_accessibility+weight_of_willingness_to_get_tested*Willingness_to_get_tested	dmnl/year	The ratio of how many people getting tested. The value is calculated as the overage number of the Willingness to get tested and the Testing accessibility considering their weights.
Time_to_change_stigma	5	Years	The time it takes for Indicated stigma to adjust. The assumption is based on the fact that social HIV stigma is a complex phenomenon that has been built over the decades, so it takes a long time to change it.
Time_to_get_information	1/360	Years	The time needed to receive information from the news and social media. The value is assumed.
Total_population	HIVnP_total+HIVpP_total	People	The number of total population.

Total_population_Data	GRAPH(TIME) Points: (2000.00, 146900000.0), (2001.04761905, 146300000.0), (2002.0952381, 145200000.0), (2003.14285714, 145000000.0), (2004.19047619, 144300000.0), (2005.23809524, 143800000.0), (2006.28571429, 143200000.0), (2007.33333333, 142800000.0), (2008.38095238, 142800000.0), (2009.42857143, 142700000.0), (2010.47619048, 142900000.0), (2011.52380952, 142900000.0), (2012.57142857, 143000000.0), (2013.61904762, 143300000.0), (2014.66666667, 143700000.0), (2015.71428571, 146300000.0), (2016.76190476, 146500000.0), (2017.80952381, 146800000.0), (2018.85714286, 146900000.0), (2019.9047619, 146800000.0), (2020.95238095, 146700000.0), (2022.00, 146200000.0)	People	The historical data of the total population in Russia from 2000 to 2022 according to The Federal State Statistics Service.
TR_Safe_sex	MAX (0, Transmission_risk_per_safe_sex_act*Safe_sex_rate_overage)	dmnl	This variable calculates the probability of a new HIV infection during one sex act with a condom.

TR_Unsafe_sex	(1-Safe_sex_rate_overage)*Transmission_risk_per_unsafe_sex_act	dmnl	This variable calculates the probability of a new HIV infection during one sex act without a condom.
Transmission_risk_per_safe_sex_act	Transmission_risk_per_unsafe_sex_act*Reduction_in_risk_with_condom_use	Dimensionless	This variable calculates a number that shows the infectivity of sex with protection.
Transmission_risk_per_unsafe_sex_act	0.02	dmnl	This external variable contains a number that shows the infectivity of sex without protection. The risk estimates for the sexual transmission of HIV, per a sex act, range widely, from 0.5% to 3.38% (HIV transmission risk: a summary of the evidence, 2012).
weight_of_Condom_accessibility	0.3	dmnl	The effect of Condom accessibility on the computation reflects its importance in Safe sex rate overage. The number is assumed.
weight_of_testing_accessibility	0.2	dmnl	The effect of Testing accessibility on the computation reflects its importance in the Testing rate current. The number is assumed.
weight_of_willingness_to_get_tested	0.8	dmnl	The effect of Willingness to get tested on the computation reflects its importance in the Testing rate current. The number is assumed.
weight_of_Willingness_to_have_safe_sex	0.7	dmnl	The effect of Willingness to have safe sex on the computation reflects its importance in Safe sex rate overage. The number is assumed.
Willingness_to_get_tested	GRAPH(Gap_between_actual_and_desired_stigma) Points: (0.000, 1.000), (0.100, 0.670320046036), (0.200, 0.449328964117), (0.300, 0.301194211912), (0.400, 0.201896517995), (0.500, 0.135335283237), (0.600, 0.0907179532894), (0.700, 0.0608100626252), (0.800, 0.0407622039784), (0.900, 0.0273237224473), (1.000, 0.0183156388887)	dmnl/year	The assumed effect of the stigma on the share of the population who is vulnerably willing to get tested. It is expected that a bigger number of stigma cause a decrease in the Willingness to get tested. The effect maximum is 1 and the minimum is 0.
Willingness_to_have_safe_sex	GRAPH(Gap_between_actual_and_desired_stigma) Points: (0.000, 1.000), (0.100, 0.49786624072), (0.200,	dmnl	The assumed effect of the stigma on the size of the share of the population who is vulnerably willing to use condoms. It is expected that a bigger number of stigma

	0.247870793649), (0.300, 0.123406500218), (0.400, 0.0614399303441), (0.500, 0.0305888671505), (0.600, 0.0152291642961), (0.700, 0.00758208677741), (0.800, 0.00377486504069), (0.900, 0.00187937786703), (1.000, 0.000935678793552)		cause a decrease in the Willingness to have safe sex. The effect maximum is 1 and the minimum is 0.

Run Specs	
Start Time	2000
Stop Time	2050
DT	1/12
Fractional DT	True
Save Interval	0.0833333333333
Sim Duration	1.5
Time Units	Years
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000