# Safe Sex and the Spread of HIV



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# SAFE SEX AND THE SPREAD OF HIV

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## RESUMO

De há muito, que a estrutura de redes sociais tem um papel importante na dinâmica da propagação de doenças. A disseminação do vírus da AIDS resulta de interações sociais complexas e de diversos fatores relacionados com a cultura, comportamento sexual, demografia e geografia, assim como depende da disponibilidade e acesso a serviços de saúde e prevenção. As redes de mundo pequeno têm sido usadas para representar interações em redes sociais. Ela postula que, a partir de um pequeno número de conexões aleatórias, a distância entre dois indivíduos quaisquer em uma população reduz-se drasticamente. Neste trabalho apresentamos alguns resultados, obtidos a partir de um modelo de simulação discreta, relativos à prática de sexo seguro e suas conseqüências para a disseminação do HIV em uma população. Este modelo de simulação é uma variação do modelo clássico de redes de mundo pequeno, adaptado para representar interações sociais e a transmissão sexual do HIV.

**PALAVARAS CHAVE. Dinâmica de propagação de enfermidades, HIV, Modelagem de saúde.**

**Área principal: Simulação**

## ABSTRACT

It has long been recognised that the structure of social networks plays an important role in the dynamics of disease propagation. The spread of HIV results from a complex network of social interactions and other factors related to culture, sexual behaviour, demography, geography and disease characteristics, as well as the availability, accessibility and delivery of healthcare. The small world phenomenon has been used for representing social network interactions. It states that, given some random connections, the degrees of separation between any two individuals within a population can be very small. In this work we present some results, derived from a discrete event simulation model, for the consequences of safe sex practices on the spread of HIV within a population. This simulation model uses a variant of the small world network model to represent social interactions and the sexual transmission of HIV.

**KEYWORDS. Dynamics of disease propagation. HIV. Health care modeling.**

**Main area: Simulation**

## 1. Introduction

Sexually transmitted diseases (STD) are known to be the source of many common health problems throughout the world and despite the growth of industrialised civilisation and sophisticated medicine they are still rampant today. HIV is having a serious impact on many societies and economies. Unlike the other big killers of the world, HIV kills people at the most productive time of their lives, mostly young adults and parents of young children. The world must once again learn crucial lessons about what works best in preventing new infections and improving the care for people living with HIV.

At the beginning of the HIV epidemic, there was a great urge to look for historical models as a means of studying the epidemic by finding its similarities with other well known STDs. Consequently, traditional epidemiological models, that largely disregard the complex patterns and structures of intimate contacts, are still used for quantifying the spread of HIV worldwide. Although one must acknowledge the evolution and contribution that this family of models gave to epidemiology, these models are out of date for dealing with HIV as they do not take into account important factors such as partnership formation and dissolution, duration and strength of partnerships, sexual behaviour changes and concurrency.

It has long been recognised that the structure of social networks plays an important role in the dynamics of infectious disease propagation. Social network theory focuses on understanding social structures and its consequences by using the relations between people as the unit of analysis where measurements are taken. Social network analysis is used widely in the social and behavioural sciences as an abstract representation of interpersonal relationships that aid in the study of populations. The spread of STDs, particularly HIV, results from a complex network of social interactions, sexual behaviour, culture, demography, geography and disease characteristics, as well as the availability, accessibility and delivery of healthcare.

The small world phenomenon (Watts and Strogatz, 1998; Watts, 1999), also known as six degrees of separation, has been used for representing dynamic network interactions. It states that, given some random connections, the degrees of separation between any two individuals within a population can be very small compared with its size.

The original small world models are unsuitable for modelling social networks and the spread of infectious diseases. The network vertices are equally considered for rewiring or shortcuts, which are unlike the real world, since the level of interaction that an individual possesses will not be the same as for other individuals. Furthermore, the connections are equally weighted or the network is strongly connected and they do not have the ties/links properties of edges for capturing the social behaviour of an individual within the network.

The model developed here modifies the original small world model in order to accommodate differential selectivity (vertex properties), sexual behaviour (edge properties) and network properties such as performance and concurrency, fundamental for the modelling of human sexual contact network and the spread of HIV. Yet it is consistent with the general definition of the small world theory.

## 2. Description of the HIVacSim model

The HIVacSim model is proposed by Vieira (2005) and starts by defining the simulation clock $t$ that moves in $\Delta t$ steps ($\Delta t$ = month | trimester | semester | year), which guides the definition of the population and model outcomes. For the computation, one defines the number of replications (controlled by the parameter $r$), the underlying network structure for each population core group and the levels of interactions among individuals. The model then warms-up the initial population to eliminate transients, if necessary, and runs for the predefined length of interactions.

Activities associated with the dynamics of population (birth and deaths), social interactions leading to the formation and dissolution of partnerships, preventive vaccination intervention, the dynamics of sexual behaviour and transmission of HIV are evaluated for each $\Delta t$ as shown in Figure 1. The information to be transmitted through the network connections over time is the HIV infection.

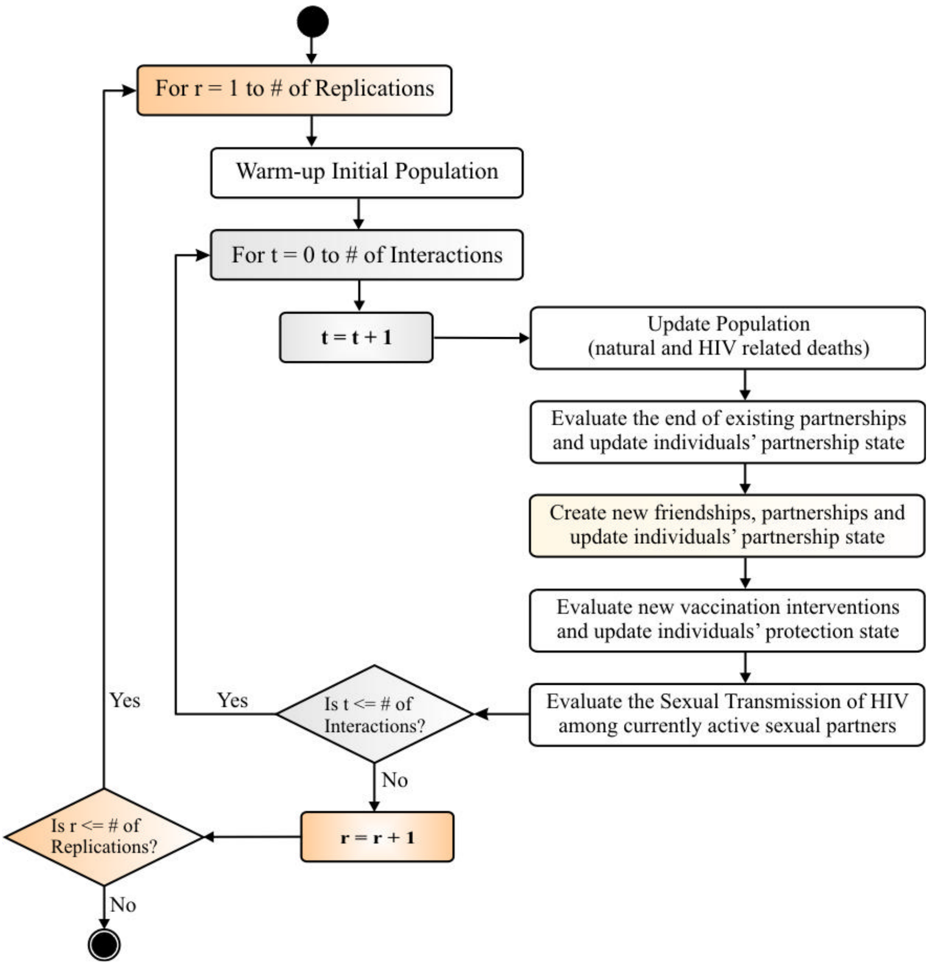


Figure 1. Model computation activity diagram.

The main activities associated with social interactions and sexual transmission of HIV are the formation/dissolution of partnership (monogamy, concurrency and duration), rate of sexual contacts, safe sex practice and the HIV transmissibility as shown below (Figure 2).

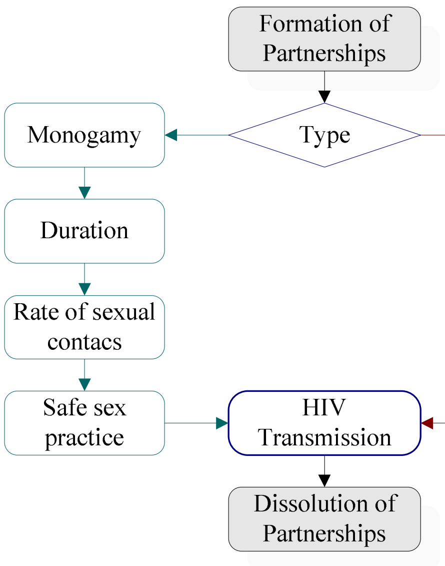


Figure 2. Sexual transmission of HIV activities.

The population characteristics are defined as a function of the simulation clock *t*, which can be tuned to reflect the data available. The level of detail to be included within the model will depend upon the availability of data. The following properties shown in Table 1 are defined as a minimum requirement.

Table 1. Population characteristics definition.

| Population structure | Parameters and probability distributions |
|---|---|
| Population identity | 1: Size n - The size of the population in each core group. |
| | 2: Age distribution - The population's age distribution used to quantify the effects of HIV infection on individuals and/or to define age based population core groups. |
| | 3: Life expectancy - The distribution of life expectancy in the population without the effects of HIV infection. |
| | 4: Gender - Proportions of female, male and homosexuals in the population, used to define partnerships within the population. |
| HIV infection status | 5: HIV prevalence - The currently estimated prevalence of HIV infection within the population. |
| | 6: HIV lead-time distribution - The lead-time of the HIV infection among people living with HIV/AIDS, used to quantify deaths caused by HIV infection. |
| | 7: HIV testing rate - The proportion of people tested for HIV infection in the population, fundamental when making decisions about treatment and preventive intervention strategies. |
| Network and social rules governing the formation of partnerships, migration, concurrency and community structure | 8: Maximum number of concurrent partnerships - Network property governing the overlapping of partnerships. |
| | 9: Probability of concurrent partnership - Population behaviour towards multiple sexual partners or extramarital partnerships. |
| | 10: Probability of a casual partnership - equivalent to small world's probability *p* - social rule governing the network structure according to the nature of the partnerships within the population. |
| | 11: Probability of looking for a sexual partner at any time - Available for partnership - social rule accounting for individuals' desire to be involved in sexual partnerships. |
| | 12: Probability of searching own group first for a casual partner - Network rule representing the community structure of the population and the cultural behaviour of individuals when looking for casual partnerships. |
| Sexual behaviour of individuals in **stable partnerships**, quantifying the strength and frequency of social interactions as well as the dissolution of partnerships | 13: Duration of stable partnerships - The distribution of length of long-term partnerships in the population (e.g. the duration of marriage). |
| | 14: Time between stable partnerships - The distribution of time between two consecutive stable partnerships. The mean time taken by individuals to find a new stable partner as described by the pair formation models (Dietz and Hadeler, 1988). However individuals can have casual partners in between stable partnerships. |
| | 15: Rate of sexual intercourse for stable partnership per unit of time - The distribution of sexual contacts, the sexual behaviour of individuals when engaged in a long-term partnership. |
| | 16: Probability of safe sex practice during sexual intercourse for stable partnership - The behaviour of individuals engaged in stable partnerships, condom use, especially relevant to those having extramarital partnerships, the bridges for HIV (Morris et al., 1996). |
| Sexual behaviour of individuals in **casual partnership**s, quantifying the strength and frequency of social interactions as well as the dissolution of partnerships | 17: Duration of casual partnership - The distribution of short-term partnerships in the population. |
| | 18: Rate of sexual intercourse for casual partnership per unit of time - The distribution of sexual contacts between individuals when engaged in a short term sexual partnership. |
| | 19: Probability of safe sex practice during sexual intercourse for casual partnership - The behaviour of individuals relating to condom use, especially among young people and those involved in multiple sexual partnerships. |

A number of results about epidemics on a small world have appeared, in particular, Boots and Sasaki (1999) analysed why some diseases are more virulent than others. They showed that the ability of pathogens to infect distant individuals in a spatially structured host population leads to the evolution of a more virulent pathogen and concluded that if the world is getting smaller as individuals become more connected, disease may evolve higher virulence. Kuperman and Abramson (2001) analysed the small world effect in an epidemiological model. They evaluated models of disease spread on different population structures and suggested an epidemic threshold for the small world parameter $p = 0.2$. They concluded that when the critical value of $p$ is reached, the system is composed of small regions of low clustering and similar local dynamics. The synchronised, periodic global behaviour then establishes itself spontaneously.

## 3. Model Validation

We illustrate the use of our model to represent a real world population and examine the properties of the underlying small world network representation using data from Brazil. A national study conducted in 2000 evaluated the sexual behaviour of the Brazilian population and perception of HIV/AIDS (Brazilian Ministry of Health, 2000). The study consisted of a face to face interview of 3,600 males and females ageing between 16 and 65 years and living in urban areas of 169 micro regions of Brazil. The micro regions were defined by the Brazilian 1996 census. The Brazilian urban population in this age range was 77,018,813 people and the sample region represents a population of 59,872,819 people, corresponding to 77.7% of this population. A similar study was conducted in 2003 by the Brazilian National STD/AIDS programme to investigate the behaviour of the sexually active population in the past six months, 14 years of age and above (Brazilian Ministry of Health, 2003). This second study focused only on sexual behaviour and safe sex practice of the population; 1,298 face-to-face interviews were conducted nationwide.

A further follow-up survey entitled the "Knowledge, Attitudes and Practices of the Brazilian Population aged between 15 and 54 years" (Szwarcwald et al., 2004) was completed in 2004. A total of 6,000 individuals were interviewed, the sample was stratified according to geographic region (macro-region): 900 interviews were conducted in the North, South and Centre-West regions, 1,100 in the Northeast region and 2,200 in the Southeast. In each of the major regions, the sample was carried out in multiple stages: States; census sectors; and households. The sectors within each of the States were selected by sampling, with probability proportional to size. The data from the second and the third studies is also available and was used to adjust the parameters fitted to the first study due to observed sexual behavioural changes during the four years gap. For clarity the data is not presented here but is reported in Vieira (2005). The way that parameters were estimated and the model was fitted is also described in detail in Vieira (2005).

We illustrate the use of the model for a multiple group representation using Brazilian data. Table 2 provides group definitions and parameters. It is important to notice the overlapping of the group definition for under 25 and married groups. In this case, being married has higher priority over age, therefore less than 25 years of age and married individuals are classified as part of the married sub group. This scenario was used to evaluate the effects of inter core group interactions on the dynamics of the sexual transmission of HIV in a small world network. For simplicity the initial HIV prevalence is kept unchanged.

A number of experiments were initially performed to validate the model, which included the evaluation of the extent to which HIVacSim represents the general theory of small world networks. Several experiments were carried out so that in each case the error bars associated with a 95% confidence interval were relatively small (e.g. Figure 3).

Table 2. Multiple group scenario definitions.

| Parameters and Probability Distributions | Group Definitions | | |
|---|---|---|---|
| | Married | Under 25 | Others |
| Population size (*n*) | 1422 | 794 | 1108 |
| Age distribution | Weibull(182.3, 336.3, 2.3) | LogNormal(144.0, 95.1, 37.0) | InvNormal(242.2, 246.9, 621.9) |
| Life expectancy (70 years) | 840 months | 840 months | 840 months |
| Proportion of females | 50% | 45.8% | 62.4% |
| Proportion of males | 50% | 54.3% | 37.6% |
| Proportion of homosexual males | 5% | 5% | 5% |
| HIV prevalence | 0.007 | 0.007 | 0.007 |
| HIV lead-time distribution | Weibull(64.3, 1.6) | Weibull(71.8, 1.6) | Weibull(64.3, 1.6) |
| HIV testing rate | 16.34% | 11.71% | 18.29% |
| Maximum number of concurrent partnerships | 5 | 5 | 5 |
| Probability of concurrent partnership | 0.06 | 0.21 | 0.14 |
| Probability of casual partnership | 0.06 | 0.40 | 0.27 |
| Probability of looking for a sexual partner | 1 | 0.78 | 0.64 |
| Probability of searching own group first for casual partner | 0.4 | 0.8 | 0.7 |
| Duration of stable partnerships | Weibull(198.2, 1.6) | LogNormal(29.8, 37.2) | Weibull(89.7 1.0) |
| Time between stable partnerships | Gamma(20.2, 1.1) | Weibull(14.9,1.1) | Gamma(24.4, 1.0) |
| Rate of sexual intercourse for stable partnership per unit time | Gamma(4.7, 1.5) | Gamma(6.5, 1.1) | Gamma(5.1, 1.3) |
| Probability of safe sex practice during sexual intercourse for stable partnership | 0.11 | 0.47 | 0.21 |
| Duration of casual partnership | Gamma(8.8, 1.1) | Gamma(5.3, 1.0) | LogNormal(9.2, 14.6) |
| Rate of sexual intercourse for casual partnership per unit time | Gamma(5.0, 1.6) | Gamma(7.1, 1.1) | Gamma(5.3, 1.4) |
| Probability of safe sex practice during sexual intercourse for casual partnership | 0.12 | 0.55 | 0.42 |

## 4. Safe Sex Practices

We illustrate the use of the model to evaluate the consequences of changes in sexual behaviour. From a modelling perspective, sexual behaviour changes must be measured not as an individual phenomenon but through relationships, appreciating the fact that sexual risk behaviour directly involves two people. The focus therefore should be directed towards selective mixing, safe sex practices, and the variations in partnership patterns such as length, strength and overlapping. Here we examine the effects of condom use on HIV transmission. Consistent condom use was shown by Weller and Davis (2004) to dramatically reduce the risk of sexual transmission of HIV infection. They estimated that compared with no condom use, consistent condom use results in an overall 80% reduction in risk of HIV transmission, with worst-case and best-case scenarios ranging from 35% to 94%. In order to illustrate the effectiveness of consistent condom use on the sexual transmission of HIV, we consider the following three scenarios:

- No safe sex – there is no condom use;
- Original – the rates of condom use for stable and casual partnerships are as found in the literature for Brazil, namely 18% and 42% respectively;
- Intervention – defines a public campaign promoting consistent condom use among stable partners as a family planning strategy which results in increasing the rate of consistent condom usage among stable partners to the same level (42%) of casual partnerships.

Figure 3 shows the impact of consistent safe sex practices on reducing the HIV epidemic (prevalence and incidence) within our model for the above scenarios.

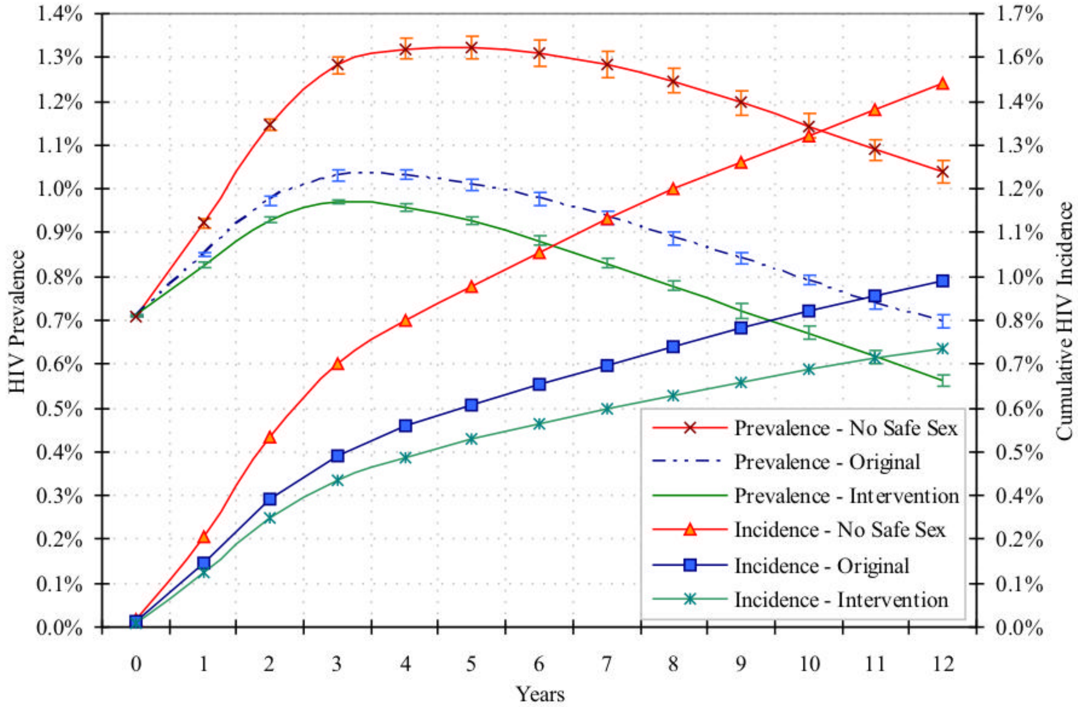


Figure 3. Safe sex practice influence on HIV transmission.

The observed use of condoms in Brazil is high for casual partnerships among young people; however it is relatively low among married couples. This result clearly illustrates the efficacy of consistent condom use in preventing HIV transmission. Additionally, the result supports the promotion of public campaigns, targeting not only the most vulnerable groups but the entire population, inducing sexual behaviour changes towards safer sex practices.

## 5. Conclusions

An infectious disease or information needs only a small amount of randomness ($p \approx 0.2$) on network interactions in order for it to spread efficiently on a local and global scale. This randomness parameter of the small world (probability of casual partnership) has a direct and non-linear effect on HIV transmission.

There is a great need worldwide to promote the evolved framework and developed model described here to a wider healthcare audience. The structure and flexibility of this model should contribute towards a better understanding of the effects of social network interactions and sexual behaviour changes on the dynamics of HIV transmission. This would help to improve the planning and management of resources to prevent HIV infection in the first place and make life for those HIV infected individuals more comfortable.

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