

# Demographic and epidemiological models for projecting HIV incidence, prevalence and mortality

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## Introduction

This work will address three recommendations of the June 1999 Geneva meeting of the HIV/AIDS Reference Group.

- 1.1 The recommendation to pursue “Studies of the temporal relationship between HIV incidence and prevalence [that] will help inform the interpretation of prevalence data to infer patterns of incidence” (Garnett 1999:5).
- 1.2 The recommendation that UNAIDS/WHO adopt approaches that will facilitate the work of “various national and international organisations needed to generate future scenarios for the epidemic” insofar as this is possible “without compromising the immediate UN AIDS/WHO objective of preparing the best possible near term estimates” (Garnett 1999:8).
- 1.3 The recommendation to develop “... models which are, on the one hand, simple enough to be usable by UNAIDS/WHO in producing estimates, but which also allow utilisation of available data on age- and sex-specific prevalence” (Garnett 1999:8).

## Specific Objectives

Before proceeding to specific research objectives we note two classes of HIV/AIDS models. The simpler epidemiological models incorporate only the infected population, with new infections generated by an “exogenously” specified new infections curve (as defined in Brookmeyer and Gail 1994:12). Epimodel (Chin and Lwanga 1991) exemplifies models of this type. The models implemented by Tim Brown (1999), which generalise Epimodel by introducing age-specificity and in other ways, are also in this class. More complex epidemiological models, like most demographic models, incorporate the entire population, uninfected as well as infected. They thus make it possible to generate numbers of new infections “endogenously” as a function of numbers of currently infected and uninfected persons, perhaps disaggregated by pertinent characteristics. The differential equation models described in Anderson and May (1991:122-128) and Daley and Gani (1999:20-52) exemplify these models. We refer to the first type as “infected population only” models, the second type as “whole population” models.

The project has three primary research objectives.

- 2.1 To develop minimally complex whole population models incorporating age, sex and numbers of persons infected and not infected. The essential problem here is to incorporate age-specificity and endogenous modelling of new infections while maintaining sufficient simplicity for the model to be of use in practical empirical work.

Existing models for studying the HIV/AIDS epidemic tend to extremes. At one extreme we have the elegant but limiting simplicity of Epimodel. At the other extreme lie the formidably complex IWG and Oxford Group models which allow populations to be partitioned into sexual activity classes (e.g. Anderson and May, 1991:290-303). Complex models that embody detailed demographic and epidemiological structure are potentially superior representations of actual HIV/AIDS epidemics, but their application is limited by the difficulty of understanding and applying them and by the difficulty of finding adequate statistics for the many parameters they incorporate.

We think it is important to develop models of intermediate complexity, partly for their potential in practical application, and partly as a conceptual bridge between simple and complex models. A research issue of particular practical importance is the extent to which simple models can be made to approximate more complex models.

- 2.2 To explore the extent to which the new infection curves generated by these models recapitulate the various functional forms for the new infection curve assumed by the “infected population only” models. Classical epidemiological models provide some guidance here, but with limited provision for age-specificity given currently available data (Ades and Nokes, 1993; Fontanet et al, 1998).
- 2.3 To explore the interface between HIV/AIDS models and population projection calculations aimed at describing the long term demographic impact of HIV/AIDS. The driving concern here is to improve on the methods currently in use, which employ ad hoc methods for distributing numbers of infected persons and AIDS cases by age and sex and do not adequately address multiple decrement issues. To meet this objective requires a model that incorporates the standard demographic age-sex distribution for a national population and a demographic-epidemiological model that distinguishes AIDS and non-AIDS deaths by age and sex.

Three subsidiary objectives support these primary objectives.

- 2.4 To develop and document a suitable alternative to the gamma distribution assumed by Epimodel for the new infection curve. The key concern here is a suitable functional form that brings infections down to a non-zero endemic level. This is not important for short term projections, but it is crucial for longer term scenarios aimed at illustrating the demographic impact of HIV/AIDS, such as those produced by the United Nations Population Division (1998). One simple alternative has already been developed and is incorporated in Release 0 (alpha

testing level) of the new UNAIDS Country Estimation Package developed by Tim Brown (1999).

- 2.5 To document the issues involved in modelling “multiple decrements” (equivalently, “competing risks”), i.e., deaths from AIDS and deaths from other causes. Brookmeyer and Gail (1994:93-94) discuss competing causes of death in connection with incubation period distribution, but the issue has not been adequately addressed in the modelling literature. This issue is not important where the prevalence of HIV/AIDS is low but may be important in those countries where prevalence of HIV and mortality from other causes are very high.

The essential problem is that death rates from competing causes over any finite time period cannot be specified independently because an increase in the risk of dying from one cause reduces exposure to risk of death from other causes and therefore decreases the rates of death from these other causes. The actuarial and statistical literature contains theoretical solutions, but model implementation requires suitable discrete approximations.

- 2.6 To document the relationship between (i) the partial differential equation formulation of whole population models used by epidemiologists (e.g. in the case of AIDS, Anderson, May and McLean 1994) and (ii) the discrete population projection calculations used by demographers (e.g. Bongaarts, 1990). The latter may be regarded as providing a numerical solution to the former. This is not well understood, however, and explication will facilitate understanding and co-operation between demographers and epidemiologists.

## **Approach**

This work looks forward to the development of practical tools for estimation, analysis and projection. We will therefore lean toward simpler models, and will test models against empirical data at each stage of development. The project addresses long term recommendations of the reference group, so we expect the primary audience to be members of the reference group and other persons concerned with modelling HIV/AIDS and its demographic impact. Data will be drawn from the HIV/AIDS Surveillance Data Base available on the World Wide Web at <http://www.census.gov/ipc/www/hivaidsn.html>.

Model implementation will be carried out on spreadsheets (Excel) and in Splus (Venables and Ripley 1994). In the preparatory phase of our work we will familiarize ourselves with the constructs used in the UNAIDS Country Estimation Package (CEP). When documenting our own projection model, we will draw attention to similarities and differences in inputs, outputs and procedures between our model and the CEP.

To further the aim of increased understanding and co-operation between demographers and epidemiologists we aim to make this project a model for continuous and open communication of work in progress. In preparing this proposal we have secured input from numerous working group members in the preparation of this proposal, though of

course we are solely responsible for its content. Before project work begins we will implement a mailing list, to which Reference Group members and other interested persons may subscribe. Work in progress will be made available to interested persons by posting files to a World Wide Web site (<http://www.gfeeney.com/aidsmodel/>).

Throughout the work, beginning with this proposal, we will keep in close touch with key individuals with complementary expertise, including Tim Brown (University of Hawaii), Geoff Garnett (University of Oxford), Neff Walker (UNAIDS), and Hania Zlotnik (UN Population Division).

## **Output**

Project output will include (i) a detailed report of progress on the research objectives including exploratory empirical applications and (ii) documented computer files for all work. The first phase, a draft report on model development and computer implementation, would be completed by the end of December 1999. The second phase, the final report, including further background and empirical applications, would be completed by the end of February 2000.

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