ASSA MULTI-STATE SELECT POPULATION MODEL

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ABSTRACT

This paper reports on a multi-state model being developed by the AIDS Committee of the Actuarial Society of South Africa to assist actuaries with modelling the impact of HIV/AIDS on a population whose members are selected from a larger population in some way. It discusses basic modelling issues and describes the model and how one would use it. The paper also includes an illustrative application to an industrial company. Finally, the paper concludes with an indication of what work still needs to be done on the model.

KEYWORDS

HIV; AIDS; multi-state; modelling; sub-population

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1. INTRODUCTION

1.1 Extensive work has already been undertaken by the AIDS Committee of the Actuarial Society of South Africa with regards to the modelling of the spread of the AIDS epidemic within the South African population. The results of the ASSA2000 model are consistent with both the antenatal clinic data and the number of reported deaths (Dorrington, 2000). However, projection models like ASSA2000 describe the spread of HIV/AIDS at a national or provincial level, and are not designed to assess how AIDS could spread in a sub-population which is selected in some way (e.g. assured lives or employees of a company). Furthermore, such "population models" do not lend themselves to answering questions such as what happens to HIV prevalence levels and death/disability rates if antiretroviral therapy is provided to the members of a sub-population.

1.2 Up until now, actuaries have often had to adapt a population model when required to produce results at a sub-population level. Whilst we accept that appropriate HIV incidence rates should be derived (and adapted) from such population models, population models cannot be used to measure the "selective effect" of being included in a particular group, and many cannot be used to assess the profile of the HIV positive population by stage of disease.

1.3 It was with these considerations in mind that the AIDS Committee set about designing a model specifically for projections of select populations.

1.3.1 The intention was to design a model to be used for:

- risk rating of group life, PHI and capital disability benefits (by studying the death/disability rates produced by the model);
- mortality additions for both reserving and pricing of individual life policies;

- risk rating of medical insurance benefits and PHI benefits (by studying the number of lives within the various stages of disease);
- assessing the cost of providing antiretroviral therapy to members within the sub-population group;
- assessing the impact of AIDS on companies, their employees, the cost of benefits provided to employees, etc.

1.3.2 It must be stressed, however, that the sub-population model does not remove the need for a general population projection model. Population models are easier to calibrate, are essential for national planning purposes, and provide the key input for the sub-population model in the form of HIV incidence rates.

1.4 Substantial progress has been made on this project although there is much work that still needs to be done. This paper reports on our efforts to date. This has been done in some detail in order to outline the intricacies involved in constructing and using a model of this nature. Readers requiring more detail or background to either the model or the epidemic in general and in South Africa are referred to the original project report on the development of the model (Johnson, 2000) or an earlier version of this paper which included several long appendices (Rosenberg *et al*, 2000).

1.5 Although the model has been developed to model the impact in South Africa, it can, as easily be 're-parameterized' to model the impact on select populations in other countries provided the data is available.

2. BASIC MODELLING ISSUES

2.1 *Defining the model output and model structure*

2.1.1 Ideally a select (or sub-population) model should be useful in the following contexts:

- employee benefits
- medical schemes
- AIDS consulting
- economic and demographic applications.

This requires that certain features be built into the model.

2.1.2 Firstly, the main workforce decrements (death, disability, ill-health retirement, normal retirement and withdrawal (resignation or retrenchment)) need to be allowed for in the model. In addition, the population of former members of the select population needs to be modelled, since some employers may need to know the impact of AIDS on (inter alia) ill-health retirement pensions and deferred benefits to former members.

2.1.3 Secondly, it is necessary to model separately the *entrants* into the select population. In many cases the force of HIV incidence after entry into the select population is likely to differ from the force that applied before entry. (For example, if the select population is the population of a major urban centre, and most of the entrants to the select population are from rural areas, the force of incidence after entry is likely to be higher than the force prior to entry). It would be unrealistic to assume that HIV prevalence rates among new entrants are the same as those in the select population – hence the need for the separate modelling of the two groups.

2.1.4 Thirdly, the model requires an HIV staging system that is flexible enough to allow for the modelling of all major HIV/AIDS medical expenses. Alternatively, the phases of the HIV staging system could correspond to stages of

decline in productivity and increase in absenteeism. This output may be of interest in modelling the impact of the epidemic on the productivity of a company.

2.1.5 When modelling medical scheme benefits it is necessary to consider not only medical expenses in respect of each member, but also the cost of HIV/AIDS benefits paid for members' dependants. However, the modelling of the family unit is beyond the scope of the model at this stage, and this feature has therefore not been included in the model. Features such as the modelling of fertility and AIDS orphans (which may be needed in economic and demographic applications) have also not been included at this stage.

2.1.6 Figure 1 is a graphical representation of the framework for the sub-population model. The select population is confined to individuals between the ages of 15 and 64 (the assumed age range of sexual activity), and it is assumed that it is entered through some selective process (such as recruitment or immigration). The modes of increment that apply will depend on the population being modelled. A workforce population, for example, would only be entered through recruitment.

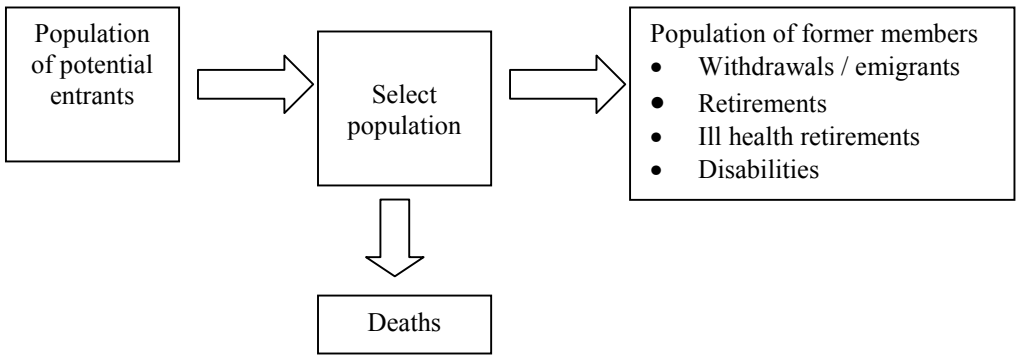

Figure 1: The general framework for the sub-population model

2.2 *Identifying the factors that affect HIV prevalence and incidence*

2.2.1 South Africa is experiencing a generalized pattern II (heterosexual) AIDS epidemic. Generalized heterosexual epidemics are common in developing countries, particularly those in sub-Saharan Africa, and South and South-East Asia. Countries in South and Central America are also experiencing generalized AIDS epidemics, although in these countries homosexuals and intravenous drug users also make up a substantial proportion of the HIV positive population (Whiteside and Sunter, 2000). The model presented in this paper, although applicable outside of the South African context, may be less applicable in countries experiencing pattern I (homosexual and intravenous drug user) AIDS epidemics. This is so because the risk factors affecting prevalence in a pattern II epidemic differ from those affecting prevalence in a pattern I epidemic. In South Africa the most significant of these factors are (not necessarily in order of significance) income, occupation, employment status, race, gender, age, region and whether urban or rural. The application of these factors to the South African context is discussed below.

2.2.2 Although, as a general rule, the poor and unemployed are most at risk of becoming infected, it would be incorrect to assume that prevalence is necessarily a monotonically decreasing function of income. There is evidence both from South Africa (Wilkinson, 1999) and other African countries (Piot *et al*, 1994) to suggest that

prevalence can be high amongst the better off, and there is also evidence that certain occupations (e.g. those associated with long separations from family and accommodation in single-sex hostels) are associated with higher prevalence levels.

2.2.3 It has been argued (van den Heever, 1998) that instead of race, models should use socio-economic factors such as income, type of dwelling and education as risk factors. While there may be some merit in this augment, the relationship between most socio-economic variables and infection is unclear, and there is a paucity of prevalence and mortality data stratified by these variables.

2.2.4 In addition, data from the antenatal clinic surveys, published up until 1996 (DNHPD, 1994, 1995 and 1996), and elsewhere, indicates that prevalence is highest in the black African population, and much lower in the other race groups. The prevalence in the coloured population is low but rising relative to that in the black African population, while the prevalence in the Asian and white population groups appears to be almost negligible. To a certain extent the epidemic in the latter two groups is likely to include a significant homosexual component.

2.2.5 The level and pattern of prevalence by age differ between men and women, with the male prevalence levels ranging between 70% and 90% of those of females, depending on the maturity of the epidemic. Male prevalence tends to be at its highest in the 25-35 age range and spread into the older ages, while female prevalence is usually highest in and concentrated around the 20-24 age range.

2.2.6 Levels of prevalence vary significantly between South Africa's provinces. The epidemic is most advanced in KwaZulu-Natal with prevalence expected to peak at close to 40%. This is followed by five provinces which not only lag KwaZulu-Natal to various degrees, but are also expected to plateau at around a 5% lower level. These, in turn, are followed by three provinces with significantly lower levels of prevalence.

2.2.7 Modellers often simply assume that the same prevalence curve will fit all provinces, provided suitable time lags are chosen. However, evidence is beginning to appear (Dorrington, 2001) that suggests that the prevalence rates in the various provinces can be expected to plateau at different levels.

2.2.8 Little investigation has been conducted locally into the difference between urban and rural levels of HIV prevalence, but what research there is suggests that initially urban prevalence significantly exceeded rural prevalence (Webb, 1994; and McAnerney, 1994). However, with the country's developed transport infrastructure and entrenched migrant labour system, the gap between the two is fast disappearing (Dorrington, 2001). The AIDS Committee is in the process of developing a version of the ASSA2000 model to model the impact of the epidemic in countries where there are clear differences between the epidemics in the urban and rural areas (Dorrington and Schneider, 2001).

2.2.9 Generally actuaries do not consider all of the above rating factors in pricing group and individual business. It was decided to construct a model which would specifically take into account age, job grade (or alternatively income or education level), gender and possibly race. Other sources of heterogeneity, such as region and industry, could be accounted for by running the model separately for each sub-group.

2.2.10 The AIDS Committee has debated whether it is socially desirable and practical to include race as a factor in the model. While race is a factor that is significantly correlated with prevalence levels, many argue that it is not appropriate to use race in pricing individual and group insurance. Although it was resolved that there were situations which could need race to be modelled separately, the model developed

thus far does not contain any stratification by race. Obviously the user who requires further subdivisions can simply run the model separately for each sub-group.

2.3 *Modelling survival*

2.3.1 Three issues need to be tackled when modelling survival of people infected with HIV: the staging system (i.e. the number of stages and what identifies each), the demographic and medical factors expected to affect survival, and the survivor function used to model the time spent in each stage of the disease.

2.3.2 Most staging systems for disease progression involve three or four stages, and are based on either laboratory measures (e.g.. viral load and CD4 count) or on clinical criteria (i.e. symptoms displayed). In the model described here, allowance has been made for four stages of disease. The parameters were set in accordance with the WHO Clinical Staging System (Maartens, 1999), based on data from a study of individuals attending HIV clinics in Cape Town (Davidse, 2000).

2.3.3 The model takes into account the effect of age, gender and job grade on survival.

2.3.4 There is substantial evidence to suggest that age affects the rate of disease progression, the elderly being subject to higher rates of AIDS morbidity and mortality (Pezzotti *et al*, 1996; Chaisson *et al*, 1995; Lungren *et al*, 1994). The model allows for the median survival in each HIV stage to vary with attained age.

2.3.5 It is unclear, from a review of the literature, that gender has an effect on survival, and hence the survival parameters for females in the sub-population model have been set equal to those for males.

2.3.6 There is also no evidence to suggest that, once socio-economic factors have been controlled for, race has any significant effect on survival (Alaeus *et al*, 1999, Chaisson *et al*, 1995).

2.3.7 It is clear from the literature that antiretroviral drugs can significantly improve survival prospects, and access to this treatment is greater among individuals of higher socio-economic status. However, it is not clear whether income and education have an effect on the rate of disease progression when access to medical care and antiretroviral treatment are controlled for. (Hogg *et al* (1994) and Chaisson *et al* (1995), for example, present contradictory findings in this regard). In parameterizing the model, it was assumed that job grade does not have an effect on the median term from infection to death independent of the effect that it has on access to antiretroviral treatment (the model does, however, allow the rate at which HIV positive individuals initiate antiretroviral treatment to vary according to their job grade).

2.3.8 One of the most important factors to consider when comparing South African survival patterns with those from developed countries is the effect of tuberculosis (TB) on survival. In low-income urban communities dual TB-HIV infection is very common, and it is estimated that up to 50% of HIV positive South Africans will die from TB (Kinghorn and Steinberg, 1998). The findings of Del Amo *et al* (1999) suggest that when running the model for populations with high TB prevalence levels, a lower overall median survival should be assumed (although the term in the "AIDS sick" phase is likely to be greater, because tuberculosis tends to occur earlier in the course of disease than other opportunistic illnesses).

2.3.9 Lack of access to medical care undoubtedly results in HIV positive individuals dying of opportunistic infections, and even non-opportunistic infections, prior to the onset of severe immunosuppression (Maartens *et al*, 1997). Thus one would tend to assume shorter median survival terms in developing countries than would be the norm in developed countries.

2.3.10 The effect of antiretroviral therapy on survival depends on three factors: (a) the combination of antiretroviral drugs the individual is treated with, (b) the stage of disease in which treatment is initiated, and (c) the degree to which the individual adheres to the prescribed course of medication. It is assumed that an individual initiating treatment is moved into one of four stages representing different levels of disease progression under antiretroviral treatment. These can be described as "asymptomatic with undetectable viral load", "asymptomatic with detectable viral load", "experiencing AIDS-related complexes" and "sick with AIDS". The rates of transition into these stages on initiation of treatment are assumed to depend on the type of treatment protocol (parameters have been set separately for double and triple drug regimens), and the stage of disease in which antiretroviral treatment is started. The assumed rates of transition between the four phases in subsequent periods can be varied to reflect higher or lower rates of adherence, but the rate of adherence is not an explicit parameter in the model. This multi-state framework for modelling disease progression is illustrated later in Figure 2.

2.3.11 Finally one needs to choose a parametric form for the survivor function used to model the term in each stage of disease. While Weibull and Gompertz distributions offer flexibility and provide a good fit to HIV survival data (Polakow, Dunne and Whitworth, 2001), they require a model that allows rates of transition between stages of disease to vary according to duration in the current stage. Although the first version of the model developed used a Weibull distribution to model survival in each stage of disease and only three stages (Johnson (2000) and Rosenberg *et al* (2000)), it was found to be extremely complex and slow. More recent versions of the model have used the exponential distribution to model the term spent in each stage of disease (this effectively means that the rates of transition out of each state are constant, and this simplifies programming significantly). This four-stage exponential model for survival (pre-antiretroviral treatment) is fairly common (see Haberman and Pitacco (1999) and Longini *et al* (1989)).

2.3.12 Although it is quite likely that survival times in each of the four HIV stages are not independent, the nature of this dependence is not at all clear. Thus, currently, for the sake of programming simplicity, independence has been assumed.

3. Description of the Model

3.1 *Overview of the sub-population model*

3.1.1 The select population model is a spreadsheet program based on a multi-state model of HIV disease progression. Three population groups are modelled within this spreadsheet:

(1) the select population (focus is restricted to those between the ages of 15 and 64 - the assumed ages of sexual activity),
(2) the population of potential entrants into the select population, and
(3) the population of former members of the select population (split by mode of decrement).

3.1.2 The incidence rates in each of these three population groups are obtained from the ASSA2000 model (described by Dorrington (2000)), and are tabulated as from 1980 (though the ASSA2000 model effectively assumes zero HIV incidence prior to 1985). The user may allow for constant adjustments to these rates in respect of

- some "overall" factor, such as the effect of being employed in a particular industry,
- job grade,
- gender (the user may expect the ratio of male to female incidence in a particular population to vary from that assumed in the ASSA2000 model), and
- time leads or lags.

These adjustments will, in general, be different for each of the three population groups in 3.1.1.

3.1.3 The approach is therefore to keep the construction of prevalence estimates in the population of potential entrants independent from the modelling of incidence rates in the select population. Not allowing for this separation, and effectively assuming the same rates of incidence for the two populations, would make the model less applicable in situations where incidence rates in the population of potential entrants are significantly different from those in the select population (for example, in workforce populations where successful AIDS education programmes have been implemented by employers, and the effect of the improvement in the rate of incidence is confined to the workforce population).

3.1.5 The model requires the division of the relevant population into two overlapping stratifications. The first stratification is according to what shall be referred to as the *demographic cohort*. A demographic cohort is defined in terms of the age last birthday (on the previous first of July), job grade and gender of its members. There are 50 age groups (ages 15 to 64), five job grades and two sexes. This gives a total of 500 demographic cohorts.

3.1.6 Secondly the population is stratified according to *stage-treatment cohort*. Such a cohort is defined in terms of the HIV state of its members (uninfected, HIV stage 1, HIV stage 2, HIV stage 3, HIV stage 4, ART stage 1, ART stage 2, ART stage 3 or ART stage 4).

3.2 *Modelling the entrants to the select population*

3.2.1 It is necessary to calculate, for each demographic cohort, the proportions of the new entrants to the select population in each stage-treatment cohort. The progression of the epidemic is tracked through a single demographic cohort (allowing for the ageing of the initial cohort) to produce prevalence rates (and percentages in each stage of the disease) for each year from 1980 to 2019. The model is based on the assumption that the prevalence at time t, among a cohort of lives who were all clear at age x, t years ago, is

$$\frac{\int_0^t \exp\left(-\int_0^s g(x+u)du\right) g(x+s) \cdot {}_{t-s}p^{+}_{x+s} \cdot {}_t(ap)_x \, ds}{\int_0^t \exp\left(-\int_0^s g(x+u)du\right) g(x+s) \cdot {}_{t-s}p^{+}_{x+s} \cdot {}_t(ap)_x \, ds + \exp\left(-\int_0^t g(x+u)du\right) \cdot {}_t(ap)_x}$$

where

$g(x)$ is the force of HIV incidence at age x

${}_tp^{+}_x$ is $\left(1-{}_tq^{+}_x\right)$, where ${}_tq^{+}_x$ is the independent probability that an individual infected at age x will die within t years from AIDS

${}_t(ap)_x$ is the probability of survival from decrements other than AIDS-related death (Gregson et al, 1996).

3.2.2 The ${}_t(ap)_x$ term cancels if it is assumed that the independent rates of decrement other than AIDS death are the same for those who are HIV positive and those who are clear (an unrealistic assumption – the non-AIDS mortality rate and the disability rate may be either higher or lower among HIV positive individuals than among clear individuals). The inaccuracy introduced by this assumption can be partially compensated for by adjusting the "probability of entry" parameters. The "probability of entry" parameter for a given HIV stage is the ratio of the probability of entry for a potential entrant in that stage, to the probability of entry for a potential entrant who is not HIV positive. The "probability of entry" parameters are thus used to represent the selective process that may be applied to those seeking to enter the population. For example, employers requiring job applicants to pass a medical examination before employing them may expect to recruit relatively few individuals in the later stages of HIV disease.

3.2.3 A VBA routine runs each demographic cohort through the model described and records, for each demographic cohort, the proportions in the different stages of disease in each year. The model does not allow for the initiation of antiretroviral therapy in the population of potential entrants (i.e. it is assumed that none of those entering the select population are on antiretroviral therapy). This is a shortcoming, but given that individuals receiving antiretroviral therapy are unlikely to change jobs, it may be an acceptable assumption in the modelling of workforce populations.

3.2.4 Results in this component of the model are not stratified by job grade - i.e. the routine described in 3.2.3 works with "ungraded" cohorts. It is assumed, for new entrants in each job grade, that prevalence levels and proportions in the different stages of disease are constant multiples of the corresponding rates for the "ungraded" cohort (the user can also allow for leads or lags between the different grades). The chief advantage of doing this is that it removes the need to model grade changes in the VBA routine described above, and reduces the amount of output that needs to be stored.

3.3 *Modelling the select population*

3.3.1 The following is a graphical representation of the basic multi-state model used as the foundation for the ASSA Select population model.

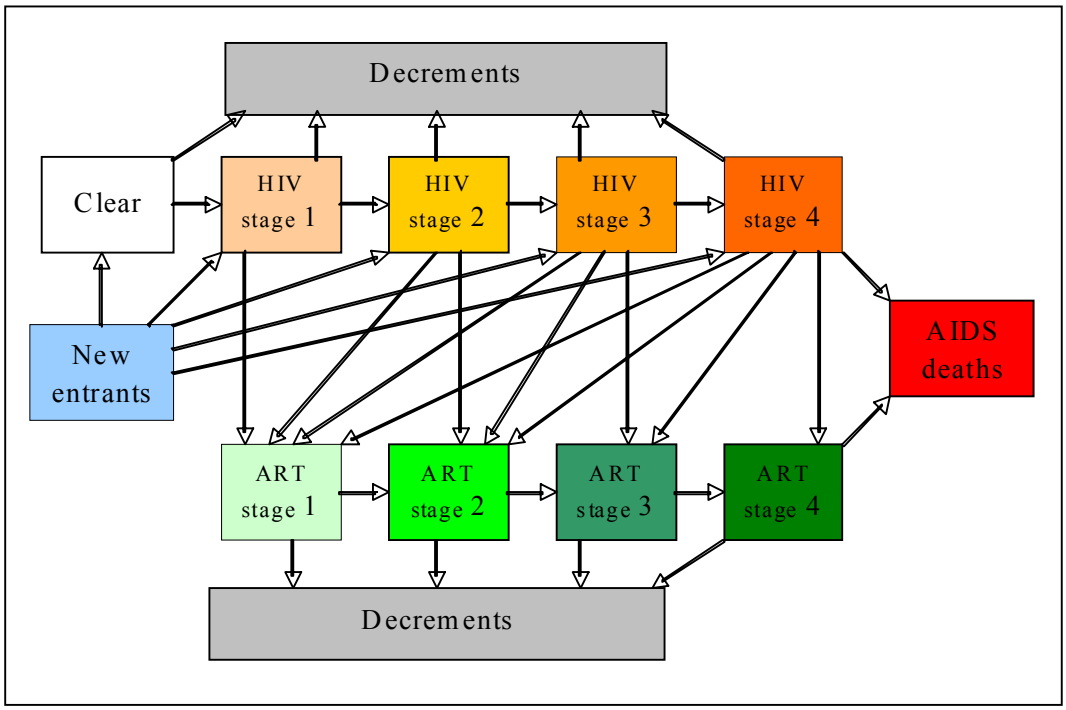

Figure 2: The multi-state model

3.3.2 The "decrements" referred to in the above diagram include non-AIDS mortality, disability, ill-health retirement, normal retirement (the model also allows for early retirement, but not for late retirement) and voluntary withdrawal. These five decrements will be referred to collectively as the *non-AIDS decrements*.

3.3.3 Several sets of assumptions and settings need to be specified in the model – these are discussed below.

3.3.4 *Settings*

3.3.4.1 There are two settings that need to be specified. These are the population growth setting and the antiretroviral treatment (ART) modelling setting.

3.3.4.2 The population growth setting gives the user the option, in modelling population growth, of either assuming numbers of new entrants to the population in each year, or assuming a percentage growth rate for the select population. If the former setting is chosen then numbers of entrants must be entered for those years over which the user intends to run the model. If the latter setting is chosen then a percentage growth rate must be entered.

3.3.4.3 The ART modelling setting is selected if the user is interested in modelling the initiation of antiretroviral therapy (for example, if an employer wants to conduct a cost-benefit analysis for different antiretroviral protocols).

3.3.5 *Calendar year definitions and age rate intervals*

Outputs from the ASSA2000 model are in respect of calendar years starting 1 July and ending 30 June (so, for example, the 1985 incidence rate will be the rate of infection between 1 July 1985 and 30 June 1986). Since the select population model derives from the ASSA2000 model, it is necessary to use the same calendar year definitions in the select population model. The projection is therefore assumed to start on 1 July of the calendar year chosen. Ages in the ASSA2000 model are defined in

terms of age last birthday, and thus the select population model also uses age last birthday.

3.3.6 *Promotion rates*

It is assumed that, for each year, the only movements that can occur between grades are movements from one grade into the grade one level up (we ignore demotions and promotions into grades more than one level up in one year). Promotion rates are allowed to vary according to gender, age and stage-treatment cohort.

3.3.7 *Demographic assumptions*

3.3.7.1 At the start of the projection (i.e. the year in which the epidemic is assumed to enter the select population) the number of individuals in each demographic cohort is entered. A problem that often arises is that the demographic profile of the select population is only known at the current time, and not at the time when the epidemic was assumed to enter the population. This problem can be overcome in one of two ways. The first way is to assume that the demographic profile of the population in the "start year" is the same as that at the current time, and to set the assumptions regarding the profile of new entrants in such a way that the demographic profile of the select population is more or less preserved when the model is projected from the start year up to the current time (a special algorithm has been created to allow the user to do this). The second way is to set an arbitrary demographic profile (preferably the current profile) as the starting demographic profile, to run the model up to the current year, and then to re-specify the numbers in each demographic cohort (using the current profile) while preserving the stage-treatment profile of each demographic cohort. The user can perform this "re-weighting" using an "update and re-weight" routine written in VBA.

3.3.7.2 The proportions of the new entrants in the different job grades are assumed to vary from age band to age band, and between men and women.

3.3.8 *Survival assumptions*

The median term in each HIV and ART stage is allowed to vary by age band, job grade and gender. Rates of initiation of antiretroviral treatment are specified, and may also vary by age band, job grade and gender (as well as by the current HIV stage).

3.3.9 *Rates of decrement*

3.3.9.1 Independent rates of non-AIDS mortality, disability, ill-health retirement, withdrawal and retirement are entered for each of ages 15 to 64. The user may allow these rates to vary according to job grade, stage-treatment cohort and gender (though the treatment of non-AIDS mortality differs, as described below). The user may also assume a constant addition to disability and ill-health retirement rates for those in the different stage-treatment cohorts. (This feature was included because rates of AIDS-related disability and AIDS-related ill-health retirement are more likely to be constant with respect to age than they are to be constant proportions of the age-specific non-AIDS disability/ill-health retirement rates).

3.3.9.2 Non-AIDS mortality rates are specified separately for men and women, and mortality rates in each job grade are assumed to be a weighted average of "heavy" and "light" mortality rates. The weights are varied between the job grades to reflect lower mortality rates at higher skill levels (as an example: for job grade 1 we might use 75% of heavy mortality and 25% of light mortality, but for job grade 5 we might use 100% of light mortality and 0% of heavy mortality).

3.3.9.3 In the body of the model, movements between the various states are calculated. The decrements, increments and cohort changes in each year are calculated in the following order:

(1) Individuals initiating ART (changing treatment cohort)
(2) Changes in HIV stage or ART stage and deaths from AIDS
(3) Non-AIDS decrements (decrements other than death from AIDS)
(4) Grade changes
(5) Age changes
(6) New entrants

} Changes in demographic cohort

A VBA routine is used to generate these numbers for each demographic cohort, and the changes in the demographic and stage-treatment profile of the select population over time can thus be tracked.

3.4 *Modelling the former members of the select population*

The former members of the select population can be modelled together with the "active members" of the select population, essentially by creating additional demographic cohorts in the select population model. This, however, results in a model that is considerably slower than the model that tracks only the active members, and thus far the version developed to track former members only applies to those exiting the select population due to disability (because this is important from the point of view of modelling PHI benefits). Work is currently being undertaken to extend this "former member model" to those leaving the workforce for other reasons.

4. CALIBRATING THE MODEL AND SETTING THE DEFAULT PARAMETERS

Users who do not have empirical data for the population with which they are working are likely to struggle to enter many of the parameter values that the model requires. It is therefore necessary to set the parameters in the model to default to values that would be expected for an "average" population, and to include in the accompanying documentation recommended parameter values under different scenarios. The model has been parameterised using data from a number of sources and represents our best guess of the current "average".

4.1 *Non-AIDS mortality rates*

The "light" non-AIDS mortality rates are from the SA85 – 90 Light Mortality Table (Dorrington and Rosenberg, 1996), and the "heavy" non-AIDS mortality rates are from the 1985 African Mortality Table (Dorrington *et al*, 1999).

4.2 *Other non-AIDS decrement rates*

Withdrawal rates, ill health retirement rates and early retirement rates were obtained from tables commonly used in pension fund valuations. These rates vary from company to company, but the rates given in the model can be regarded as "typical". Disability rates were assumed to be the same as ill health retirement rates.

4.3 *Median terms in the HIV stages*

These parameters were obtained from a study that applied a Markov model to data collected from HIV positive individuals attending clinics affiliated to the University of Cape Town (Davidse, 2000). The medians fitted by Davidse were adjusted slightly to remove the effect of the unusually high rate of tuberculosis

incidence in the Western Cape, and to allow for biases inherent in the estimation of stage 1 survival. There is a lack of research into long-term rates of survival under antiretroviral treatment (highly active antiretroviral treatment (HAART) was only introduced in 1996), and it has thus not been possible to set the parameters for the ART stages with any degree of certainty.

4.4 *Adjustments to HIV incidence and prevalence rates*

These were estimated by calibrating the model to the results of an HIV prevalence survey conducted by a light manufacturing company. While these results may be regarded as representative for an "average" company, it will probably be necessary to produce separate sets of parameters for different industries.

5. RUNNING THE MODEL

5.1 *Introduction*

5.1.1 The first step in any projection is to check whether the assumptions for the population of potential entrants are reasonable. If any changes are made to these assumptions, the routine referred to in 3.2.3 must be run in order to ensure that the profile of the new entrants reflects the new assumptions.

5.1.2 The projection for the select population starts on the last 1 July for which the entire select population is assumed to be HIV negative. The user sets the initial assumptions and then runs the model for a specified term (the term of the projection will depend on the length of time for which these assumptions apply). The user should make necessary changes to the assumptions and then run the model for the period until the next set of parameter changes are necessary. The cycle continues until all the necessary output has been generated.

5.1.3 If the select population consists of individuals working in different industries or different provinces, it may also be necessary to run the model separately for each province or industry. This should only be necessary if differences between provinces or industries are expected to be significant (for example, one would expect prevalence levels in the Western Cape to differ significantly from those in KwaZulu-Natal even after age, gender and job grade have been adjusted for).

5.2 *Allowing for interventions*

5.2.1 There are two types of interventions that may need to be modelled: HIV/AIDS education programmes aimed at reducing the rate of HIV incidence; and medical interventions aimed at improving the survival of those who are HIV positive.

5.2.2 *HIV/AIDS education programmes*

5.2.2.1 Although it is unclear how effective HIV/AIDS education programmes are, the model has the capacity to allow for a change in HIV incidence (the rate at which new infections occur) resulting from such a programme. If the user wishes to allow for a reduction in incidence rates following the launch of a particular programme, the incidence adjustment factors for those sections of the workforce most affected by the programme can be lowered.

5.2.2.2 Education programmes are not the only means of achieving a reduction in the rate of HIV incidence. Evian (1991) recommends

- making condoms generally available,
- providing effective STD treatment, and

- phasing out single-sex hostels and providing family accommodation.

These interventions can also be modelled by lowering the incidence adjustment factors. Interventions introduced at a national level (as opposed to a workforce level) can also be allowed for by recalculating the incidence rates in an appropriate manner using the ASSA2000 model, and entering these into the select population model.

5.2.3 *Medical interventions*

The intervention that is likely to be most effective in improving the survival and productivity of HIV positive individuals is the provision of antiretroviral therapy. By changing the ART initiation rates and the rates of transition into and between the ART stages, the user can examine the costs and benefits of this provision under different scenarios.

5.3 *Incorporating sample data*

The user of the model will be faced with one of three scenarios regarding data.

5.3.1 *HIV testing and questionnaire data available*

5.3.1.1 If HIV testing is conducted in the select population, this information can be used in calibrating the model. It is assumed that if HIV testing is conducted, every tested individual will have completed a questionnaire capturing basic demographic data (age, job grade, gender and province) and possibly other information (for example, information on sexual behaviour or type of accommodation).

5.3.1.2 The crudest approach to incorporating this data is to obtain estimates of the prevalence level in each quinquennial age band, in each job grade and in each gender group. The incidence adjustments for the select population and the prevalence adjustments for the entrants can then be altered and the model rerun until the prevalence rates produced by the model roughly match the observed prevalence rates.

5.3.1.3 This approach is only valid if the sampling mechanism is unbiased (i.e. the number sampled in each demographic cohort is roughly proportional to the cohort size). If the sample is biased, then the user could conduct a logistic regression to determine the prevalence level in each demographic cohort. Using the *actual* proportions of the population in each demographic cohort, the results could then be weighted to obtain average prevalence rates for each age band, job grade and gender. The model can then be calibrated against these.

5.3.1.4 The approach can also be refined if a stepwise logistic regression, applied to the data, shows that there are other explanatory variables (for example, province) that significantly affect prevalence rates. In this case the select population could be divided into groups corresponding to the different levels of the factor, and the select population model could then be calibrated and run separately for each group. The model outputs could then be aggregated to obtain the required outputs for the population as a whole.

5.3.2 *Mortality or morbidity data available*

The numbers of deaths and disabilities predicted by the model can be compared with the numbers observed (if this information is available), and the model parameters may be revised if they would appear to be inappropriate. Care should be taken when using such data that biases introduced by selective decrements (e.g. people resigning before claiming) are properly identified and accommodated.

5.3.3 *No HIV testing or mortality/morbidity data available*

In this case the user will need to use the default parameters, or rely on the recommended incidence and prevalence adjustments in the documentation that will ultimately accompany the model.

6. FINANCIAL VERSION OF THE MODEL

6.1 In addition to the demographic model discussed above, we are currently developing a financial version of the model. The purpose of this is to allow companies to assess the impact of AIDS on their company profits. The model currently projects various costs for each year into the future, namely:

Employee Benefit Costs: The model includes group life assurance, group life with lump-sum disability as an 'accelerator' benefit, lump-sum disability, long-term disability income protection), short-term disability income benefit and funeral benefits.

Medical Costs: The model projects the medical costs incurred in each year for each individual in the different HIV and ART stages, taking medical inflation into account.

Company Expenses: The model allows one to measure the impact on productivity and sick leave, recruitment and retraining, and the cost of implementing, and maintaining an HIV/AIDS programme.

6.2 *Employee Benefits Costs*

6.2.1 All benefits and costs are expressed as a multiple and percentage of salaries respectively. The model allows for salary inflation in the projection of costs.

6.2.2 *Lump sum costs*

6.2.2.1 Group life assurance costs are calculated by multiplying the benefit amount by the number of deaths for each cohort of lives and then applying an expense and profit loading. When there is a lump sum disability 'accelerator' benefit then we don't include the deaths of the disabled lives. The costs can be split between AIDS and non-AIDS deaths.

6.2.2.2 Lump sum disability costs are calculated in the same way, but by multiplying the number of newly disabled lives (AIDS and non-AIDS) in each cohort by their respective benefits.

6.2.3 *Income costs*

6.2.3.1 In the case of income disability benefits, the benefit (for example, 75% of an employees salary) is multiplied by an annuity factor for each individual cohort of new disabilities (separately for AIDS and non-AIDS disability).

6.2.3.2 The annuity factor is calculated using a built-in annuities model. The annuities model calculates the annuity factor by going through the future lifetime of each newly disabled cohort. The model takes into account all the same features of the cohort's future lifetime that the demographic model does, including movements between the different HIV and ART stages. The annuity factors for Clear disabilities allow for the possibility of future infection of the individual. The annuity factor also makes allowance for withdrawal from the disabled state, for example, recovery of the disabled life (however, at present these lives are not returned to the working population under consideration).

6.2.3.3 The annuities model can be used for varying terms, for example, to normal retirement age in the case of long-term income disability and a fixed term in the

case of short-term disability. However, the annuities model currently has the shortcoming that it doesn't allow the benefits to change over the term of disability, although simple escalations of benefits can be allowed for.

6.2.3.4 The annuities model also does not allow for termination rates to change by duration since disability. The annuities model itself can allow for this, but the select model does not, for its disabled lives. Therefore to ensure consistency we have excluded variable termination rates by duration since disability.

6.2.3.5 A further shortcoming of the annuities model is that it does not allow decrement assumptions to change over time. The annuities model runs one demographic cohort at a time, rather than one year at a time (unlike the select model), and it is difficult to change the assumptions by year within each demographic cohort.

6.3 *Medical Costs*

The model projects HIV/AIDS medical costs for each year into the future crudely by multiplying the number of lives in each HIV/ART cohort by the estimated medical costs in that cohort. The projections allow for medical inflation, expressing the costs as a percentage of salaries, so that all costs are a percentage of salaries. Unfortunately the model does not build family units for each member and thus cannot allow properly for the costs of dependants.

6.4 *Company Costs*

6.4.1 AIDS-related recruitment and retraining costs, expressed as a percentage of salaries, are calculated by multiplying the expected cost, as a multiple of salary, by the number of AIDS deaths and new AIDS disabilities.

6.4.2 AIDS-related productivity and sick leave costs, expressed as a percentage of salaries, are calculated by multiplying the number of lives in each HIV and ART stage by the 'percentage reduction in productivity' (expressed in terms of the member's salary) for the corresponding stage. The user would need to obtain the 'percentage reduction in productivity' parameters by speaking to company doctors and by investigating sick leave data.

6.4.3 HIV programme costs are calculated as the cost of implementing an HIV programme in the year it is implemented and then expressed as a percentage of salaries. Costs also take into account the salaries of dedicated staff and other ongoing costs of the programme.

6.5 Other costs not accounted for that will be looked at in the future are those of compassionate leave (to attend funerals or perhaps to care for someone at home) and over-time pay.

6.6 The above AIDS-related costs are then summed to give the total amount, as a percentage of salaries, that AIDS will cost the company. The costs can then be compared with the AIDS costs associated with various intervention strategies.

7. CASE STUDY

7.1 *Background*

7.1.1 As part of an agreement which hopefully will lead to the AIDS Committee of the Actuarial Society of South Africa (ASSA) getting access to prevalence data they agreed to put together a team to project the impact of HIV/AIDS

on the workforce of a listed South African health and chemical manufacturing company ("Company A") with over 10,000 employees, employed throughout South Africa. In particular the Committee was asked to consider the financial implications of providing antiretroviral therapy (both dual therapy and highly active antiretroviral therapy) to Company A's employees and their spouses, over the next 10 years. The AIDS Committee made use of the model to carry out the exercise. The results presented below illustrate the usefulness of the model.

7.1.2 Unless otherwise specified the currency used is the South African Rand, as at September 2001.

7.2 *Summary employee profile*

The charts below summarises the distribution of Company A's employees by job grade, age group, and gender.

Table 1. Distribution of employees by job grade, age band, race and gender

Females Age Band	Unskilled	Semi-Skilled	Skilled	Lower Management	Senior Management	Female Total
15-19	12	6	0	0	0	18
20-24	154	162	24	4	0	344
25-29	291	589	72	51	16	1019
30-34	382	624	128	44	22	1200
35-39	460	618	165	69	35	1347
40-44	447	542	255	86	43	1373
45-49	315	375	197	83	37	1007
50-54	188	220	168	58	21	655
55-59	112	116	80	37	16	361
60-64	44	69	27	11	7	158
Total	2405	3321	1116	443	197	7482

Males Age Band	Unskilled	Semi-Skilled	Skilled	Lower Management	Senior Management	Male Total
15-19	7	2	0	0	0	9
20-24	75	71	10	9	0	165
25-29	133	154	55	41	33	416
30-34	160	170	42	55	73	500
35-39	140	167	31	50	88	476
40-44	106	170	38	48	96	458
45-49	84	157	37	32	66	376
50-54	66	94	26	31	81	298
55-59	27	59	14	14	50	164
60-64	18	13	4	2	16	53
Total	816	1057	257	282	503	2915

7.3 *Assumptions*

7.3.1 The key assumptions are listed below. In order to test the reasonableness of our assumptions, we compared the expected death and disability experience (both from AIDS and non-AIDS related causes) to that which actually occurred since 1998. Unfortunately the raw data from the company was inconclusive and had to be treated with caution. Only the male deaths showed a clearly increasing trend. However, pre-benefit testing results while also inconclusive as to the level of the prevalence, confirmed the upward trend.

7.3.2 This is not unusual in South Africa, as many employees resign prior to death/disability from AIDS (and hence forgo their terminal benefits) due, in part, to the stigma currently associated with the disease in South Africa. Hence the assumptions below represent a blend of our best estimates and results from the analysis of the raw data provided to us.

7.4 *Selective effect of employee grade on HIV sero-conversion rates*

To model the sub-population HIV sero-conversion rates, we took a proportion of the population average sero-conversion incidence rates (derived from the ASSA2000 Lite model) and applied a multiplier to these population incidence rates. We assumed a zero time lag in these incidence rates and the multipliers listed below.

Table 2. Multipliers used to adjust incidence rates from ASSA600

Annual income (in South African Rand Sep 2001)	Description	Rate of infection, as % of rate of infection in the general population
< 42 500	Unskilled	100%
42 500 - 77 500	Semi-skilled	50%
77 500 - 102 500	Skilled	25%
102 500 - 137 500	Lower management	10%
> 137 500	Senior management	7%

7.5 *Median term in each HIV+ state (no antiretroviral therapy)*

7.5.1 In addition to the selective effect of grade on incidence rates, the model has the flexibility to allow one to adapt the median terms by grade, sex and age, for each of the HIV+ stages. In this example, we made adjustments for age, but not grade or gender.

7.5.2 The term spent in each stage is modelled using an exponential distribution. The table below shows the median terms in each HIV stage for individuals between the ages 30 and 39, assuming no antiretroviral treatment is received.

Table 3. Median term to death by HIV state (prior to the use of ART)

Stage	Description	Median term (months)
1	HIV+ Asymptomatic	32
2	HIV+ Early disease	19
3	ARC	28
4	AIDS sick	15

7.5.3 Figure 3 provides a graphical representation of the assumed pattern of survival for an individual who has just sero-converted (ignoring non-AIDS mortality), showing the proportion in each of the stages.

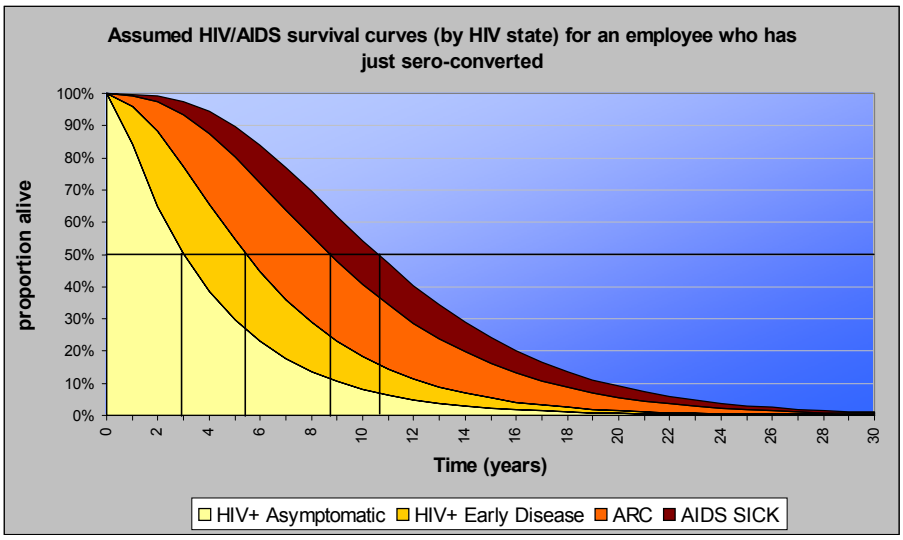

Figure SECARÁBIGO3: Proportions of HIV+ individuals in different stages of disease, by duration since infection

7.6 *Assumptions relating to the application of antiretroviral therapy (ART)*

7.6.1 In order to demonstrate how the sub-population model handles the effects of anti-retroviral therapy on survival times (and hence prevalence/death rates) we had to make assumptions relating to:

- the median term to death within each ART state,
- the proportion of lives who initiate ART treatment in each year, and
- the type of treatment (e.g. dual therapy, triple therapy or HAART) that would be modelled (this would affect both survival times and possibly adherence levels).

We calculated the costs under two treatment scenarios: dual therapy and highly active antiretroviral therapy. For an explanation of how the ART survival assumptions are allowed for in the model see section 2.3.10.

7.6.2 To allow for the consideration that not all lives will initiate therapy (either because they are unaware of - or do not wish to know - their HIV status, or for other reasons) we assumed that the annual rates of ART initiation for individuals in the different HIV stages are:

Table 4. Rate at which ART is initiated pa

Clinical stage	Rate at which ART is initiated (p.a.)
Acute infection (asymptomatic)	0%
Early disease (asymptomatic)	2%
Late disease (ARC)	10%
AIDS sick	20%

7.6.3 We allowed for longer life expectancy of employees receiving anti-retroviral treatment. The median term to death for an employee initiating ART, at each HIV state, is summarised below:

Table 5. Median term to death for an employee initiating ART, at each HIV state

Stage in which treatment is initiated	Expected median survival (in years) on initiating ART	
	Dual therapy	HAART
Early disease (asymptomatic)	8.5	13.5
Late disease (ARC)	6.0	10.0
AIDS sick	3.5	8.5

7.6.4 The large improvement in survival on initiating HAART is because HAART regimens are often successful in reducing viral concentrations to undetectable levels. It must be emphasized, however*, that HAART is a relatively recent development, and there is little medical evidence to show what the long-term survival benefits of HAART are (although evidence does show very encouraging short-term benefits)*. The parameters set out above represent our best estimates of the long-term improvement in survival, but they are subject to much uncertainty.

7.7 *Allowances for AIDS related withdrawals, prior to death*

We assumed that 1% of employees in asymptomatic stage, 5% of employees in ARC state and 65% of employees in AIDS sick state, become disabled each year. (This is in addition to our standard non-AIDS disability rates).

7.8 *Allowances for new employees*

7.8.1 We assumed that new members are hired in such a way that the overall demographic profile of the workforce remains stable over time.

7.8.2 As new recruits undergo medical testing before being hired (but no HIV test is performed), it is likely that doctors should be able to assess whether an individual is sick with AIDS, based on the symptoms that the prospective employee is displaying. When analysing the HIV sero-prevalence levels of the company over time, we assumed new entrants to undergo a medical exam (but not an HIV test) which would result in the following conditional probabilities of being recruited.

Table 7. Relative proportions of new entrants who are HIV positive

Probability of entry for an individual in the given HIV stage, as a % of the probability for an uninfected individual				
Relative probability of entry	HIV+ Asymptomatic	HIV+ Early Disease	ARC	AIDS sick
	100%	100%	50%	5%

7.8.3 The above table reflects the testing scenario described in 7.8.2. and the fact that, for example, AIDS sick individuals are unlikely to apply for a job (since they are unlikely to be healthy enough to work).

7.9 *Non-AIDS deaths, withdrawals and ill-health disabilities*

Allowance was also made for non-AIDS death, withdrawal and ill-health disabilities, as well as the selective effect of grade/salary on these decrements.

7.10 *Results (no Anti-Retroviral Therapy)*

7.10.1 *Population Incidence Rates*

The first stage of the investigation was to derive population incidence rates from the ASSA2000Lite model. The graph below summarises sample *average* incidence rates by age, sex and calendar year

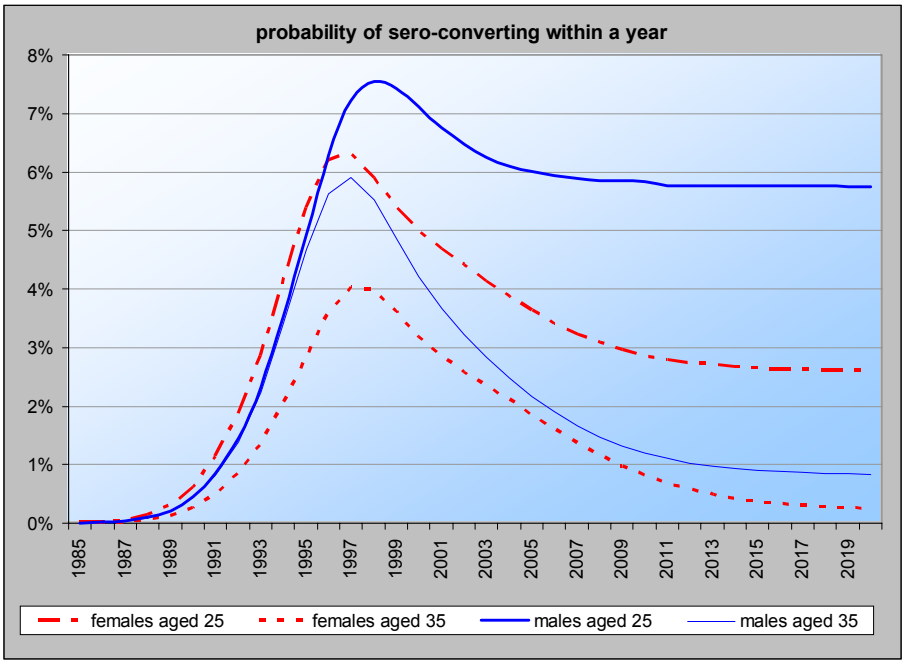

Figure SECARÁBIGO4: Average SA adult sero-conversion rates by race and calendar year

7.10.2 *Prevalence rates*

From these population incidence rates and the assumptions specified above, we were able to derive the prevalence rates (prior to the allowance for ART) for Company A's employees. The HIV prevalence rates allow for new entrants to be medically tested (i.e. tested as being fit for service, but not HIV tested prior to entry). The results are summarised in the graph below.

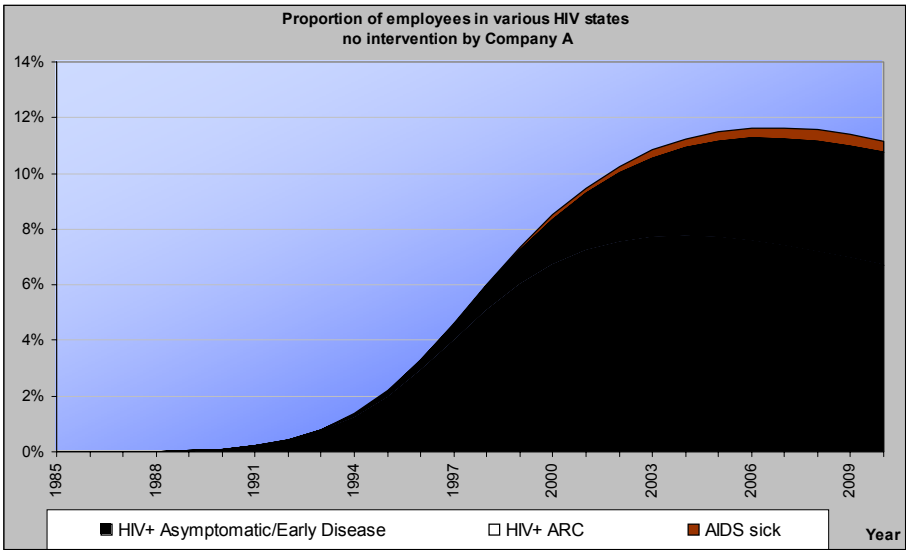

Figure SECARÁBIGO5: Company A – modelled prevalence rates by HIV state, over time (assuming ART is not provided to the workforce)

7.10.3 *Death/Disability rates*

One of the main reasons for producing a sub-population model is to project the HIV/AIDS death and disability rates so as to cost group life benefits (for example). The following curve summarises the model's output of the company's current and projected future death/disability rates from the active workforce. The increase in deaths from the active workforce is small relative to the increase in disabilities, because most of the AIDS deaths occur among individuals that have already withdrawn from the active workforce, on disability benefit.

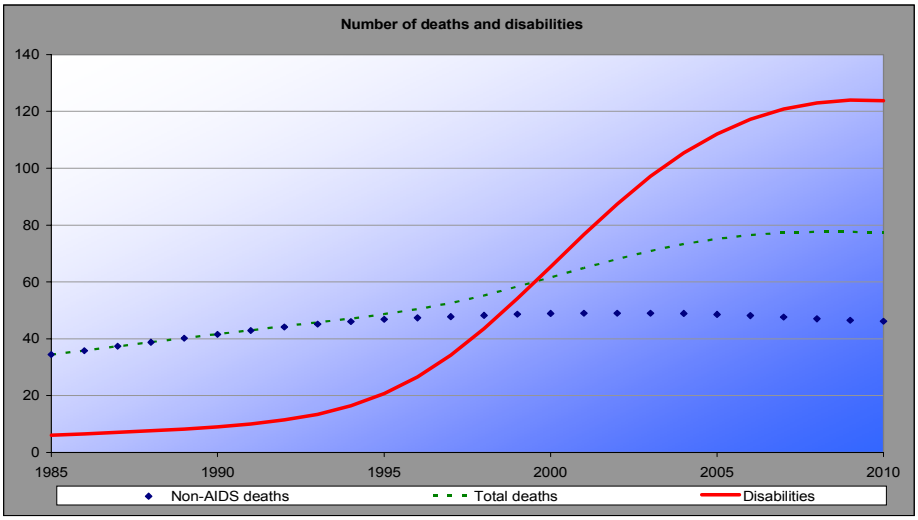

Figure SECARÁBIGO6: Company A – modelled death/disability rates

7.11 *Results (with antiretroviral therapy)*

7.11.1 *Overview*

We have allowed for antiretroviral therapy (ART) by assuming that ART (both dual therapy and HAART) is provided by Company A from 2002.

7.11.2 *Prevalence rates*

7.11.2.1 The curve below contrasts the projected HIV sero-prevalence rates both with and without ART. In all cases we have assumed that new entrants are medically fit, but not HIV tested prior to entry.

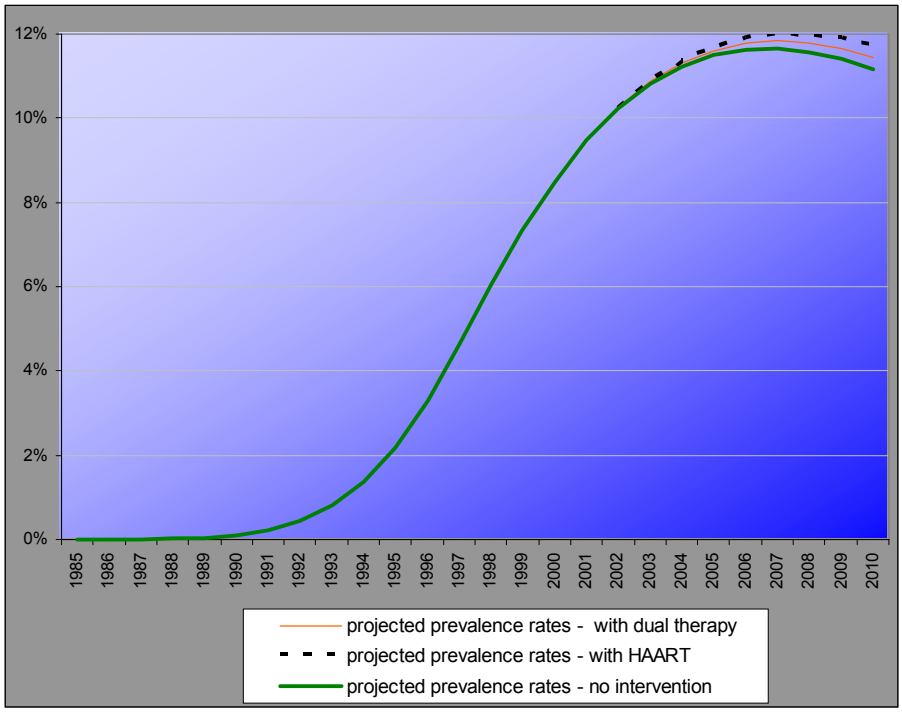

Figure SECARÁBIGO7: Company A – modelled prevalence rates allowing for two differing intervention strategies

7.11.2.2 The above figure demonstrates that by introducing antiretroviral therapy, those that are HIV+ survive longer, and hence Company A's sero-prevalence levels rise when ART is introduced.

7.11.3 *Prevalence by HIV state (allowing for ART)*

7.11.3.1 In order to determine whether it was economically viable for Company A to provide ART to their employees, we had to assess the proportion of employees who are receiving therapy over time, which is graphically demonstrated in the next graph (here we have used HAART as an example).

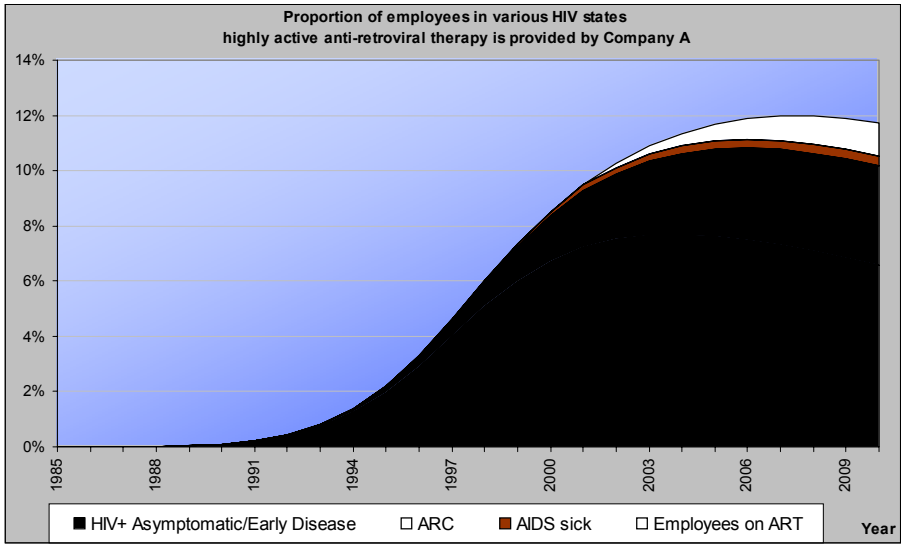

Figure SECARÁBIGO8: Company A – modelled prevalence rates by HIV state, over time (assuming HAART is provided to the workforce)

7.11.3.2 The proportion of Company A's workforce on ART (in the above figure) was then multiplied by the projected number of employees employed by the company, and the projected cost of the antiretroviral therapy, to determine the expected annual cost of ART for Company A.

7.11.4 *Death/Disability rates (allowing for ART)*

Antiretroviral therapy extends the life expectancy of recipients and therefore defers the death/disability experience of the company, as demonstrated in the next figure.

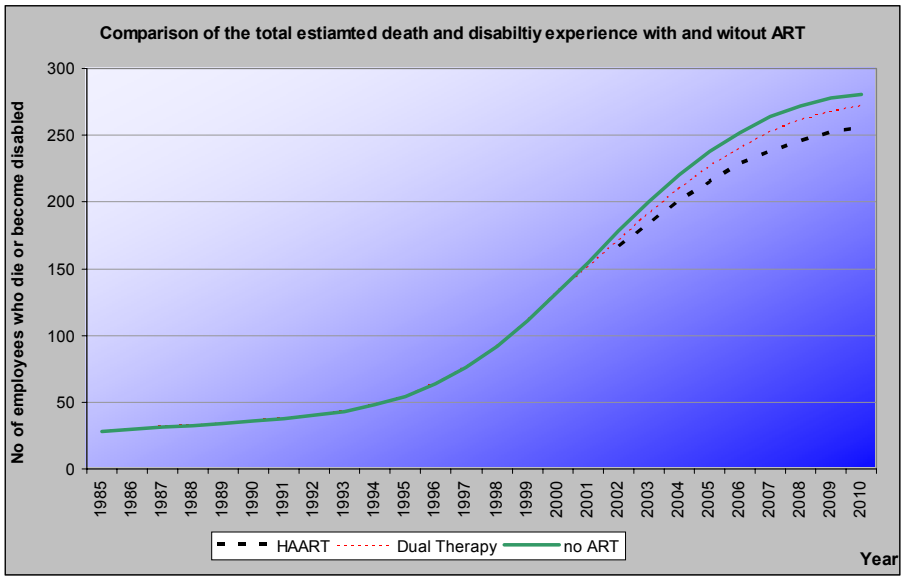

Figure SECARÁBIGO9: Company A – modelled death/disability rates (allowing for ART)

7.11.5 *Comparison of group risk rates*

7.11.5.1 Company A provides its employees with the following risk benefits:

- Three times annual salary on death.
- In the event of total and temporary disability, an income continuation benefit of 75% of basic pay, (after a 1 month waiting period) for a maximum of 11 months.
- A lump sum of three times annual salary on total and permanent disability.
- The normal retirement age is 65 for all employees.

7.11.5.2 Using the assumptions listed in 7.2 above and the benefits listed in 7.11.5.1 above, we estimated the impact of HIV/AIDS on Company A's group-risk insurance costs.

7.11.5.3 Under the "no intervention" strategy one can see that group-risk costs are expected to rise from 2.7% of salaries (pre-AIDS) to roughly 6% in 2010. By implementing an anti-retroviral treatment programme, the company can defer their group-life costs and obtain a slightly lower cost plateau (5.9% for dual therapy and 5.8% for HAART). These reductions in group risk costs are small, but this is largely a consequence of the low rates of ART initiation assumed.

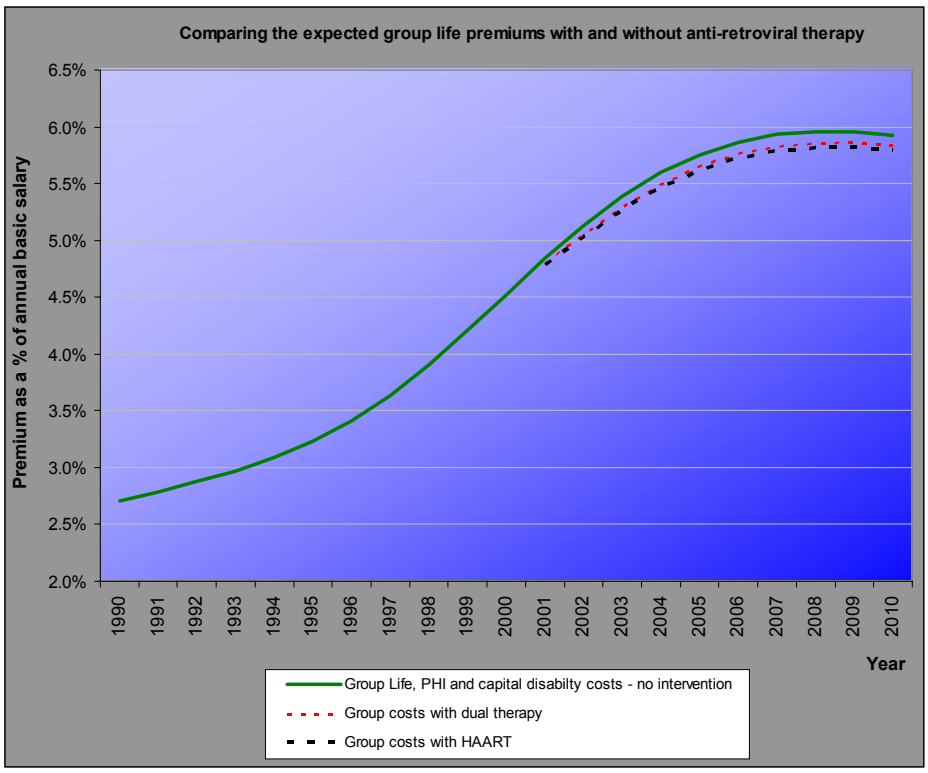

Figure SECARÁBIGO10: Group life costs as a percentage of pensionable salaries – using the various scenarios

8. CONCLUSION

8.1 The ASSA select population model is a tool that can be used to model the demographic and financial impacts of AIDS on workforce populations and on other "selected" groups. It has been developed in response to the shortcomings of techniques currently being employed, most of which are based on models used to project the impact of the epidemic at a national level. Although developed for the South African environment, it is anticipated that it may be useful in other countries experiencing generalized AIDS epidemics.

8.2 Considerable progress has been made in the development of the model, but further work is required. Most importantly, the financial version of the model still needs some work. It may also be necessary to develop separate versions of the model to model the impact of AIDS on medical schemes and pension funds. Both developments would require the extension of the model beyond the working ages, and may require further development of the "former members" component of the model. It remains to be seen whether another version of the model will be necessary for economic and demographic modelling applications.

8.3 Deriving appropriate assumptions and calibrating the model to appropriate data is an extremely difficult and a time-consuming task. This process has begun, but further work is required. Below we discuss the groups of parameters that need to be estimated and how we plan to arrive at estimates of them.

8.3.1 Incidence and prevalence adjustments need to be investigated. At this stage there is a particular need for data specific to different industries. It may also be necessary to recommend separate parameters for different provinces. Insurance HIV testing data and results from workforce prevalence surveys conducted by certain large organizations may prove useful in this regard.

8.3.2 Although there is a vast amount of research into the short-term benefits of antiretroviral treatment, little research has been conducted into the long-term rate of survival of individuals initiating antiretroviral treatment, particularly in the case of highly active antiretroviral treatment. This issue needs to be further researched before conclusions based on this component of the model can be presented with any degree of certainty.

8.3.3 It is also necessary to verify that the results produced by the model appear reasonable. This might be achieved by comparing the projections of the sub-population model to those of a simplified model. Many such simplified models are available in the industry. Sensitivity testing of parameters could also be done.

8.4 The demographic version of the model as well as a manual for its use are freely available at the ASSA website (www.assa.org.za/committees/aids/aids.htm). At this stage the AIDS Committee feel that the financial version of the model, once complete, is likely to be too complex to be placed in the public domain. Access is likely to be restricted to people who have first attended a CPD training course.

ACKNOWLEDGEMENTS

The authors acknowledge the work of the rest of the sub-committee working on the select population model (David Blecher, Munnik Botha, Dani Katz, Dominic Liber, Piet Maree, Wilfred Moyo, Thomas Muhr and Martin Potgieter) and the remainder of the AIDS Committee of ASSA.

REFERENCES

HIPERVÍNCULOALAEUS A., LIDMAN K., BJORKMAN ET AL. (1999). Similar rate of disease progression among individuals infected with HIV-1 genetic subtypes A - D. *AIDS*. **13**: 901 - 907. Cited in *AIDS Scan*. **11** (9): 15 - 16.

CHAISSON R. E., KERULY J. C., MOORE R. D. (1995). Race, sex, drug use, and progression of human immunodeficiency virus disease. *New England Journal of Medicine*. **333**: 751 - 756.

DAVIDSE A. (2000). *An analysis of the course of HIV infection using a Markov model*. Honours Research Project, Department of Statistics, University of Cape Town.

DEL AMO J., MALIN A., POZNIAK A., DE COCK K. (1999). Does tuberculosis accelerate the progression of HIV disease? Evidence from basic science and epidemiology. *AIDS*. **13**: 1151 - 1158.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT (DNHPD). (1997). *Seventh national HIV survey of women attending antenatal clinics of the public health services in South Africa, Oct Nov 1995*. Quoted in *AIDS Scan*, **9** (2): 5 - 6.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT (DNHPD). (1996). Sixth national HIV survey of women attending antenatal clinics of the public health services in the Republic of South Africa, Oct / Nov 1995. *Epidemiological comments*. **23** (1): 3 - 15.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT (DNHPD). (1995). Fifth national HIV survey in women attending antenatal clinics of the public health services in South Africa, Oct / Nov 1993. *Epidemiological comments*. **22** (4): 90 - 100.

DEPARTMENT OF NATIONAL HEALTH AND POPULATION DEVELOPMENT (DNHPD). (1994). Fourth national HIV survey in women attending antenatal clinics, South Africa, Oct / Nov 1993. *Epidemiological comments*. **21** (4): 68 - 78.

DORRINGTON R. E. AND SCHNEIDER D. (2001). *Fitting the ASSA2000 Urban-Rural AIDS and Demographic Model to 10 Sub-Saharan Countries*. A paper presented at the 24th General Population Conference, Salvador - Bahia, Brazil, 18-24 August 2001.

DORRINGTON R. E. (2001) *The Demographic Impact of HIV/AIDS in South Africa by Province, Race and Class.* A paper presented at the AIDS in Context International Conference, 4 -7th April, 2001, University of Witwatersrand.

DORRINGTON R. E. (2000) *The ASSA2000 Suite of Models.* A paper presented to the Annual Convention of the Actuarial Society of South Africa, Somerset West, 24-25 October, 2000.

DORRINGTON R., BRADSHAW D. AND WEGNER T. (1999). *Estimates of the level and shape of mortality rates in South Africa around 1985 and 1990 derived by applying indirect demographic techniques to reported data*. Medical Research Council, Tygerberg.

DORRINGTON R. E. AND ROSENBERG S. (1996). Graduation of the 1985-90 assured life mortality experience: A question of maintaining standards. *Transactions of the Actuarial Society of South Africa*. **11** (1): 91 - 144.

EVIAN C. (1991). *AIDS in the Workplace in Southern Africa*. Russell Friedman Books.

Gregson S., Donnelly C. A., Parker G., Anderson R. M. (1996). Demographic approaches to the estimation of incidence of HIV-1 infection among adults from age-specific prevalence data in stable endemic conditions. *AIDS*. **10**: 1689 - 1697.

HABERMAN S. AND PITACCO E. (1999). *Actuarial models for disability insurance*. Chapman & Hall/CRC. Boca Raton, Florida.

HOGG R., STRATHDEE S., CRAIB K., O'SHAUGHNESSY M., MONTANER J. AND SCHECHTER M. (1994). Lower socioeconomic status and shorter survival following HIV infection. *The Lancet*. **344**: 1120 - 1124.

JOHNSON L. (2000). *AIDS: Modelling the impact of the epidemic in sub-populations*. BBusSc honours project, UCT.

KINGHORN K. AND STEINBERG M. (1998). *HIV/AIDS in South Africa: The Impacts and the Priorities*. Department of Health

LONGINI I., CLARK W. AND BYERS R. (1989). Statistical analysis of the stages of HIV infection using a Markov model. *Statistics in Medicine*. **8**: 831 - 843

LUNDGREN J. D., PEDERSEN C., CLUMECK N., GATELL J. M., JOHNSON A. M., LEDERGERBER B., VELLA S., PHILLIPS A., NIELSEN J. O. (1994). Survival differences in European patients with AIDS, 1979 - 89. *British Medical Journal*. **308**: 1068 - 1073.

MAARTENS G. (1999). Clinical progression of HIV in adults. *South African Medical Journal*. **89**: 1255 - 1258.

MAARTENS G., WOOD R., O'KEEFE E. AND BYRNE C. (1997). Independent epidemics of heterosexual and homosexual HIV in South Africa - survival differences. *Quarterly Journal of Medicine*. **90**: 449 - 454.

MCANERNEY J. (1994). HIV seroprevalence in TB patients. *AIDS Bulletin*. **3** (3): 14 - 15.

PEZZOTTI P., PHILLIPS A., DORRUCCI M., COZZI LEPRI A., GALAI N., VLAHOV D. AND REZZA G. (1996). Category of exposure to HIV and age in the progression to AIDS: longitudinal study of 1199 people with known dates of seroconversion. *British Medical Journal*. **313**: 583 - 586.

PIOT P., GOEMAN J. AND LAGA M. (1994). *AIDS in Africa* (Chapter 8). Essex M., Mboup S., Kanki P. J., Kalengayi M. R. (editors). Raven Press. New York

POLAKOW D., DUNNE T. AND WHITWORTH J. (2001). Parameterisation of expected residual lifetime after seroconversion in a Ugandan sample population. *South African Actuarial Journal*. **1**: 35 - 61

ROSENBER S., JOHNSON L., SCHNEIDER D. AND DORRINGTON R. E. (2000). *ASSA Select Population Model*. A paper presented at the annual convention of the Actuarial Society of South Africa, Somerset West,

VAN DEN HEEVER A. (1998). HIV/AIDS and employee benefits. *AIDS Analysis Africa* (Southern Africa Edition). **9** (1):3 - 4.

WEBB D. (1994). Mapping the AIDS pandemic: geographical progression of HIV in South Africa (1990 - 93. *Nursing RSA*. **9**: 20 - 21.

WHITESIDE A. AND SUNTER C. (2000). *AIDS: The Challenge for South Africa*. Human & Rousseau and Tafelberg. Cape Town

WILKINSON D. (1999). HIV infection among pregnant women in the South African private medical sector. *AIDS*. **13**, p. 1783.