Modelling the Socio-Economic Impact of HIV/AIDS in South Africa

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Abstract

HIV/AIDS is a key concern in South Africa. However, its impact cannot be examined in isolation of other stresses, such as food insecurity, high climate variability, market fluctuations, and poor governance. In this paper, we present an agent-based simulation model of the social impacts of HIV/AIDS in villages in the Vhembe district, Limpopo Province, South Africa. It has been developed in the context of the CAVES (Complexity, Agents, Vulnerability, Evidence, and Scale) project. It is our understanding that modelling the complex interactions at the individual and household level will enable stakeholders to better understand the impact of stressors and potential coping strategies at the community level. The model and its preliminary results are presented to motivate discussion among the social science community.

Keywords: HIV/AIDS impact, household structure, evidence-based ABSS, social networks

1 Introduction

More than 60% of all people infected with HIV/AIDS are living in sub-Saharan Africa, even though this region has just over 10% of the world's population. In South Africa the epidemic has evolved at an astounding speed, rising from a prevalence of less than 1% among adults to almost 25% within ten years. A recent study shows the devastating toll AIDS is taking on human lives: from 1997 to 2002 the death rate increased by 62% (UNAIDS 2005). Not surprisingly, investigating the social impact of HIV/AIDS is at the top of the research agenda of the UN (UNAIDS 2004). A number of studies have highlighted the need to investigate the impact of HIV/AIDS at the communal level (see e.g. Heuveline et al. 2003, UNAIDS 2004, Foster 2005).

Agent-based social simulation is a tool well suited for an investigation of this sort since it allows for the necessary detail in modelling the effects of stresses like HIV/AIDS on social networks. Unlike conventional epidemiological models that operate on the level of whole populations and therefore concentrate on "average" behaviour, agent-based models can take the actual behaviours of individuals into account. This is a prerequisite for investigating impacts on social networks and communities. Over the last few years, this has been recognised by the life science community concerned with modelling the HIV/AIDS epidemic. A number of agent-based models have been proposed (e.g. Heuveline et al. 2003, Heuveline 2004, Teweldemedhin et al. 2004), some of which involve the effects on the structure of households (Heuveline 2004).

However, even though HIV/AIDS is a key concern, its impact in South Africa cannot be examined in isolation of other stresses, such as food insecurity, high climate variability, market fluctuations, and poor governance (Ziervogel et al. 2005). In this paper, we present the prototype model of the social impacts of HIV/AIDS in villages in the Vhembe district, Limpopo Province, South Africa. It has been developed in the context of the CAVES (Complexity, Agents, Vulnerability, Evidence, and Scale) project. This EU-funded research project aims at developing modelling procedures for the formation of social policy in conditions of uncertainty due to complexity[1]. It

[1] http://caves.cfpm.org

involves case studies in Poland, Scotland and South Africa to provide extensive qualitative and quantitative evidence with which to constrain agent-based social models linked to biogeophysical models. The model described here is the initial model for the South African case study.

In the case study area, the Limpopo region in South Africa, HIV/AIDS is one of the major stressors for people's livelihoods, together with climate variability and food insecurity, leading to a high vulnerability. Most people in the area rely on state grants such as pensions or child/orphan grants and remittances from migrant workers for their subsistence, since agriculture alone is not sufficient. Death of the family member receiving the grant or sending money home can therefore have a devastating effect on a household, to the point of dissolution. Orphan children are usually accommodated by a household in the extended family. Other strategies for coping with stressors such as resource sharing or pooling of finances also rely on social networks in the community.

2 Prototype model

The model focuses on the behaviour of individual agents as well as that of households and thus attempts to take into account both the individual interactions and the decisions taken by the households. Since field work for knowledge elicitation had to be done in parallel due to organisational constraints of the CAVES project, the prototype model is largely based on existing data from previous projects undertaken in the same region; namely the UNRAVEL project (Understanding resilient and vulnerable livelihoods in Malawi, South Africa and Zambia; Ziervogel et al. 2005) and FIVIMS-ZA (du Toit and Ziervogel 2004), a project assessing the feasibility of developing a Food Insecurity and Vulnerability Information and Mapping System (FIVIMS[2]) for South Africa. Within the framework of the latter, a pilot study was undertaken in the Sekhukhune district, whose data obtained from a detailed questionnaire was made available to our team. Unfortunately, it turned out that the data pertaining to social networks of individuals and/or households was either missing completely or aggregated in such a way that it was impossible for us to infer the necessary information. For the prototype model we thus had to make a number of assumptions, which we checked with our domain experts from SEI Oxford. These will be rectified as soon as empirical data from the field work will be available.

Social networks

The model adopts a multi-layer network approach to model the social networks. So far, two network layers are considered, one on the level of individuals and one on the level of households. Individuals are represented as agents with a network of friends. Each individual is member of a household, with one of the household members acting as the household head. Households have a network of social neighbours with whom they interact. The network is dynamic in the sense that households may disintegrate, while new ones are created, and the relationships among the members of the networks change over time. As actual empirical data on the structure of these networks is yet missing, we assumed a small-world network. This assumption is supported by several other studies conducted in the region (e.g. Quinlan et al. 2005, Salomon et al. 2000).

These social neighbours are the basis for informal savings clubs, known as *stokvels*. Members of a stokvel pay a mutually agreed sum into the club every month. The cumulative savings of the group are then rotated to each member of the group on a regular basis. After everyone has had their turn in receiving the contributions, the group may disband or start another cycle. Female household heads with higher literacy are usually the coordinators of these savings clubs (Verhoef 2001). We model this by introducing the role of 'innovators' for a certain proportion of agents. Innovators are able to initiate a savings club by inviting other agents and run the club after its formation.

Another form of pooling financial resources are the so-called funeral clubs. Households pay a monthly contribution and receive a lump sum whenever they have to pay for a funeral. Funeral clubs play an important role because death in the family not only constitutes an emotional but also a financial burden as all family members are supposed to assemble at the place where the funeral takes

[2] http://www.fivims.net/

place. Whilst there, there must be provision for food and other basic essentials (Ziervogel et al. 2005). Unlike the stokvels, funeral clubs are institutionalised and thus not initiated by individual agents. In the model this is treated by creating funeral clubs with initial funds at the start of the simulation. The number of clubs is a parameter of the model.

Orthogonally to the network layers of friends and social neighbours is the hierarchical family structure. As stated above, each individual agent is a member of a household. Households in turn form clusters which represent the extended family. This comes into play when a household dissolves due to the death of all care-providing adults, leaving the dependants (orphan children and possibly any seniors without income) behind. If this happens, an accommodating household has to be found. This search uses the family hierarchy to determine the nearest living relative who is able to accommodate the surviving dependants. If there is none in the extended family, the search is expanded to the networks of neighbours and friends.

Household income

In contrast to many other countries in Africa, South Africa has a social support system providing grants to at least some of the people in need. In the case study area, grants are a main source of income; pension grants have been found to support entire households (Ziervogel et al. 2005). A significant proportion of the grant money is spent on food, followed by transport and medical expenses. In the model we currently include four basic types of grants as listed in table 1. A component representing a state institution decides at each time step whether an individual is to be awarded a grant or not.

Grant type	**Eligibility criteria**
Child grant	For children ≤ 8 years suffering from HIV/AIDS
Orphan grant	For orphan children until the age of 15 years
Disability grant	For adults suffering from HIV/AIDS
Pension	For seniors over 55 (women) or 60 (men) years

Table 1: Grant types and their criteria

Another major source of income are remittances sent home by migrant workers to support their families (Posel 2001, Posel and Casale 2003). Modelling migration and remittances is important, as both the spread of the epidemic and the income the households receive from migrants is impacted by the prevalence of HIV/AIDS. In the current version of the model, only adult male agents are considered eligible to become migrant workers. The proportion of eligible individuals actually getting work away from the village can be set as a model parameter.

HIV/AIDS

One way to model the HIV/AIDS spread is through agents' sexual activities, which requires data through fieldwork. There have been several epidemiological models addressing this issue (e.g. Heuveline et al. 2003, Teweldemedhin et al. 2004, Palloni 1995, Salomon et al. 2000, Handcock et al. 2003). Due to lack of empirical data we have so far adopted a distribution-based approach for the prototype model, giving the incidence for every time step based on the 'Gamma' distribution (Salomon et al. 2000). This will be validated once the necessary data is available.

To model the decay in health of an infected individual, the Sigmoid (S-) function is applied. We consider an incubation period of 18 months on average and a median time of 8-9 years from infection to death, as reported by the UNAIDS (2004).

Agriculture: A combined declarative and procedural approach

To cover all agricultural aspects we obtained an agent-based cropping model from SEI (Bharwani et al. 2005), which models crop choices dependent on climate experiences and weather forecasts, the growth of the chosen crop, harvest and subsequent market transactions. We adapted this model to a package to be used as a component in other agent-based models. This included solving some of the implementation problems already identified by the SEI team. The imperatively implemented decision process was extracted and transformed into rules, so that the agents' decisions about which crop to plant when are now modelled declaratively. It is our understanding that declarative modelling is often the most appropriate technique to capture social phenomena (Moss and Edmonds 2005) whereas many physical or biological processes are best described by numerically based formalisms.

We differentiate two different types of households, poor and better off, with different sets of rules. Poor households plant mostly maize for subsistence. They try to minimise their risk, which is why they rely on the weather forecast and only experiment with planting the more expensive cash crops like butternut and cabbage on part of their plots when they've got enough money to spare. Households who are better off are basically profit oriented, so they plant only cash crops and buy their maize. Examples of the rules governing these behaviours are listed below in pseudo-code; the first two relate to poor households, the last one to wealthier households:

```
(rule choose-crop-season-1-poor-1
   (month 9)
   (household (poor true) (cash < 435))
   =>
   (plant (maize (area 0.25) (cost 0)))
)

(rule choose-crop-season-1-poor-4
   (month 9)
   (forecast dry)
   (household (poor true) (using-forecast true) (cash >= 570))
   =>
   (plant (maize (area 0.25) (cost 0)) (butternut (area 0.75) (cost 255)))
)

(rule choose-crop-season-2-better-off
   (month 1)
   (forecast dry)
   (household (poor false) (using-forecast true) (cash >= 630))
   =>
   (plant (cabbage (area 1.0) (cost 180)))
)
```

The model is implemented in Java/Repast[3], using the Repast scheduler, graphical user interface and network library. The declarative component integrates JESS (Java Expert System Shell[4]), a rule engine and scripting environment developed at Sandia National Laboratories by Ernest Friedman-Hill. We found that the most efficient way to apply JESS is to use one rule interpreter for all agents, which is run once every time step. All agents of a type share one set of rules. For every agent (in this case, household) there is a corresponding fact on which the rules operate. This results in a rule firing once for every matching fact.

Using the declarative approach enables a modeller to easily trace which rules fired under what conditions at a particular time step. This in turn allows for a better understanding of the processes inherent in a model, thus supporting not only the model's validation but also facilitating its communication to stakeholders.

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[3] http://repast.sourceforge.net/

[4] http://herzberg.ca.sandia.gov/jess/

3 First Results

In this paper, we solely present preliminary results from the prototype model. After the initial simulation runs used to verify the model implementation, we started to explore different scenarios. One such scenario investigates the effects of grants on the households. Receiving a grant affects the survival of the household significantly. Without farming, where grants and remittances remain the only source of income, any further grant helps the households cope with expenses for subsistence, health care and funerals for a much longer time.

Figure 1 shows the results of a simulation run (900 months), where children are only eligible for a grant if they are orphans suffering from HIV/AIDS. With 100 initial households and the probability of obtaining work outside the village set to 40%, the social networks of the households (top left corner of figure 1) show a high dissolution rate of initial households (green), with a significantly high number of accommodating households (blue). Membership in funeral clubs increases rapidly, as shown in the top right of figure 1, due to households experiencing an increase in the deaths of family members (bottom right chart), finally leading to dissolution of households (bottom left chart).

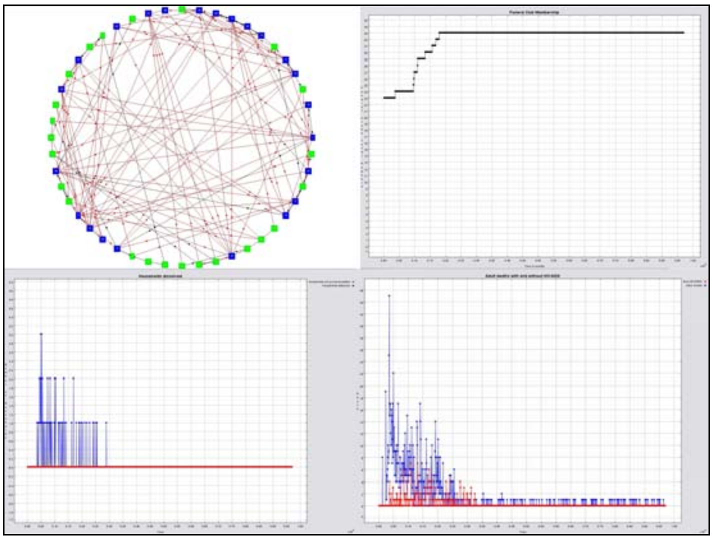

Figure 1: Impact on the households' structure with no child grant and restricted orphan grant.

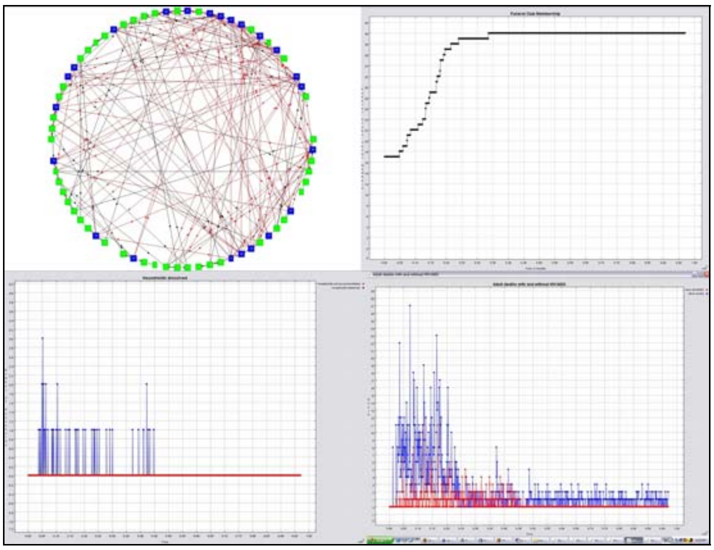

Figure 2: Impact on the households' structure with no restriction on grants.

In a different setting, as represented in Figure 2, availability of the child and orphan grants (see table 1) was not restricted. The households were able to persist much longer than in the experiment shown in Figure 1. Moreover, as the top-right chart in Figure 2 shows, the increase in the overall memberships of the funeral clubs reached its maximum much later than in the previous case.

The anecdotal evidence shows that the extended family networks are very strong. Often children stay in their parents' households even when they are married and have children themselves. Household members with no adult to look after them are often taken care of by another household in the extended family. To investigate these effects we used a further two scenarios. In the first one, each household was randomly assigned highly clustered family links. Further links are then established over the simulation run as a result of marriages in the community. In the second scenario, used as a lower bound to possible network structures, extended family ties are solely established via marriage. In both scenarios marriages are constrained by the availability of partners from the eligible age range in the community and the money (*lebola*), which the groom has to pay the bride's family.

Figure 3 shows snapshots of the simulation runs for the two different scenarios at year 30 of a 90 year (1080 months) simulation period. The simulation was set up for 200 initial households, with sizes varying from 5 to 9 members. The number of funeral clubs was set fixed to 9 and the stokvels where allowed to start over again after completing a cycle.

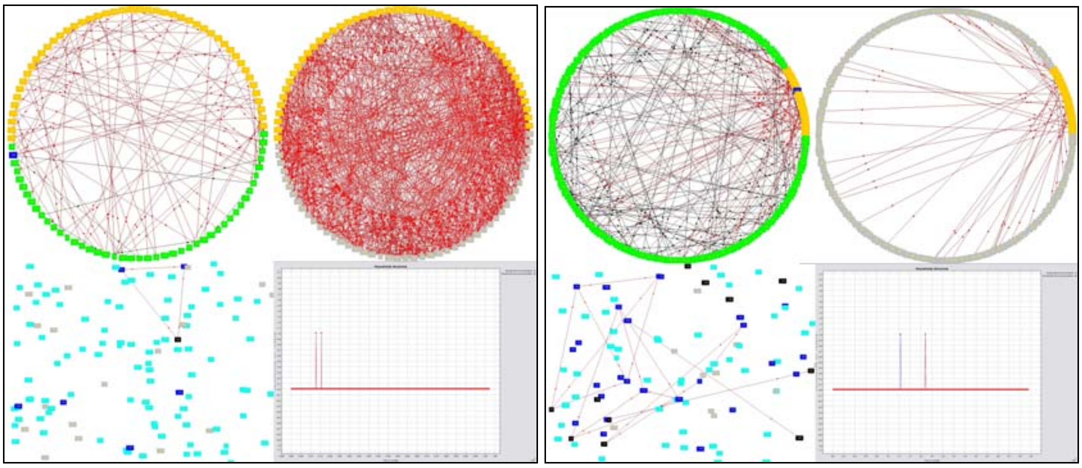

Figure 3: A snapshot of the household social links, extended family network, savings clubs memberships and time series chart. (Left) with highly clustered initial extended family links; (right) extended family links formed only as result of marriages during the run.

In the first scenario, any dissolved households could be accommodated, while in the second scenario most households failed to find an accommodator in the much sparser extended family network, as is to be expected. On the other hand, the number of savings clubs does not seem to be influenced by the density of the households' family links.

Figure 4 shows the savings clubs network at different time steps of a simulation run with the same settings. A triangle represents the smallest possible club formation among three female household heads. Note that there are cases where a third link is missing in the snapshots. This happens when a club is no longer viable and perishes in the following time step.

The deaths time series chart in Figure 5 explains why the number of stokvels declines so noticeably over time. While HIV/AIDS is the major cause of deaths occurring in the system there is also a high rate of deaths due to malnutrition and old age (large blue peaks in the middle of the time series). Increasing health expenses put additional pressure on households to pull out of savings clubs. The highly clustered frequency of deaths in the second half of the simulation run is probably a – if not the – major cause of the decline of the savings clubs memberships.

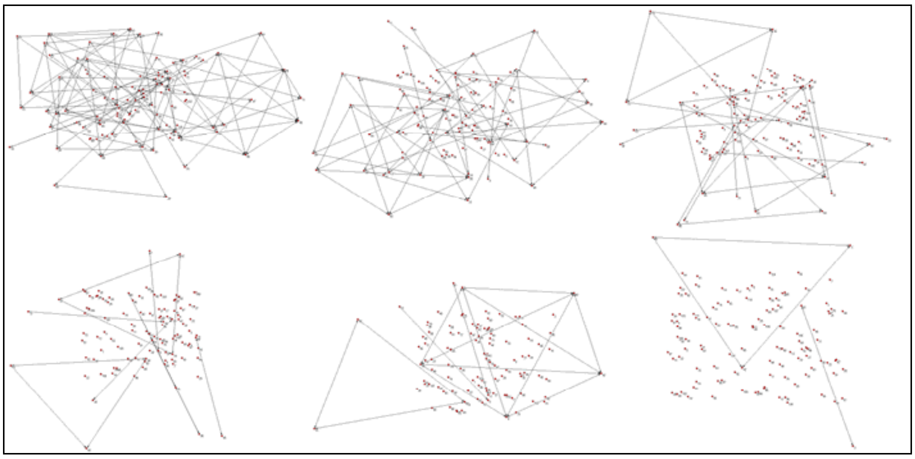

Figure 4: Snapshots of the savings club memberships for time steps from left to right: *t=125, 250, 375, 500, 750* and *875,* respectively.

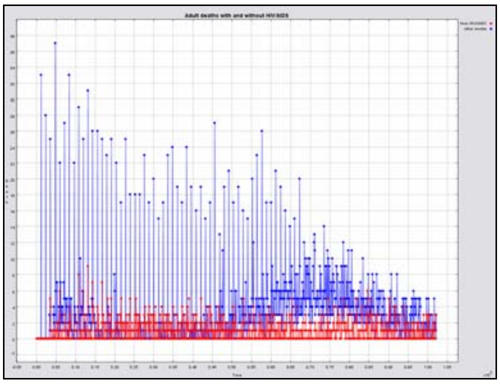

Figure 5: Time series of deaths (red: caused by HIV/AIDS) occurring during the simulation run

Conclusion and Outlook

The agent-based model presented in this paper has been developed for one of the case studies of the CAVES project. Neither case study nor model development is finished yet, so results can only be preliminary at this stage. Nevertheless, they demonstrate that the approach of agent-based social simulation we adopted to simulate the complex impacts of HIV/AIDS on social networks in rural South Africa is not only feasible but promising.

The next steps to take will include further validation of the model against newly gathered empirical evidence. This data will also be used to expand the model by incorporating enhanced decision procedures for the agents, e.g. strategies to adapt to changing circumstances in their physical and social environment.

Currently, the model is restricted to one-village scenarios. In a closed community, there are dense overlapping ties among the residents. An important next step would be to scale the model up to several villages and observe the inter-village ties. Furthermore, we need to model the role of migration/external labour in more detail. This is important in understanding the effects of remittance as well as the spread of HIV/AIDS. An important contribution of the extended family network is ‘mutual help’ which needs to be incorporated as well. We know from our domain experts that households borrow food from neighbours and introducing this feature into the model is highly significant. Finally, further developments would contribute to the understanding of dynamic social networks. Some ideas in this regard have been suggested in a different paper (Alam and Meyer 2006).

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