A Spatially Explicit Modelling Approach to Socio-economic Development in South Africa

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Abstract: South Africa finds itself at a development cross road: optimism for "high road" development is bisected by a wasteland of poverty and overpopulation. Intervention policies are largely "faith-based", even in the face of rising uncertainties surrounding population growth, HIV/Aids and resource availability. Added to this are the complexities of disparate spatial development and social scenarios, mass urbanization and immigration. In order to confront these threats, decision makers need analytical tools that can be used to explore potential intervention policies for their efficacy, desirability and inadvertent consequences in non-target sectors. Such tools should adequately address uneven spatial development across environmental, economic and social sectors over intermediate time scales. In this study, an object-oriented modelling approach was used to allow the analysis of magisterial districts [local government regimes] individually, without compromising functional interdependence between districts. Since development trends could not be modelled for individual districts due to a lack of adequate data, a trans-disciplinary dynamic system model of national development was constructed, and the equations derived for this model (LORAX 1.0) were down scaled to represent development at a district level. Agentised modelling was introduced: 1) to facilitate synchronous communication and resource exchanges between districts during analysis, and 2) to implement hypothetical intervention policies [abstracted from likely government actions], in districts where they are called for. This version of LORAX (2.0) provides a useful platform for 1) understanding sub-national trends in development and 2) for testing the consequence of likely policy interventions in a co-evolved human society.

Keywords: Agents; decision support; dynamic systems; South Africa; sustainability

1. INTRODUCTION

When the South African government renounced a century of *apartheid* in 1994, the "new" South Africa contained two worlds in one country. The first world (white) population constituted only 11% of the total population, but received 67% of the gross domestic product (GDP) [Huntley *et al.*, 1989; UNDP, 1994]. Through a legacy of capital accumulation by whites and the separate impoverishment of blacks, the third world (black) population has stagnated in demographic transition, and has been placed at the wheel of South African population growth [Huntley *et al.* 1989].

With the current population being expected to double by 2020, concerns have been raised over the ability of the agricultural sector to match rapidly increasing food demand. Only 13% of the entire land area is arable and less than 35% receives more than 500 mm of rainfall/annum. Despite these environmental limitations, much agricultural activity has been established in unsuitable regions, leading to soil loss, desertification and substantial economic losses during periodic droughts, as were experienced during the 1980's [Huntley *et al.*, 1989].

These economic losses, together with collapsing mineral prices and rapid natural population growth, aggravated by illegal immigration from neighbouring countries, have caused the GDP per capita to decrease by 30% since 1980. The corresponding increase in unemployment has catalysed rapid urbanisation, said to rival that of Mexico City. Of these economic growth nodes, Gauteng has, against all environmental odds, attracted the most industrial development due to rich mineral deposits in the area. The Gauteng-metropolis currently accounts for 60% of the GDP, despite covering a mere 2% of the land surface. Much of the workforce employed in the Gauteng mines consists of labourers migrating seasonally from the underdeveloped former homelands [Huntley *et al*., 1989].

This pattern of male migration has largely been blamed for the estimated HIV prevalence of up to 30% in the metropolis and the former homelands [Lurie, 2000; Williams *et al.*, 2000]. Despite predictions that the HIV pandemic may reach proportions that could ruin the labour-dependant economy through its disproportionately large impact on the economically active age group [Centre for Health Policy, 1991], the HIV/Aids issue has continued to receive short shrift from the South African government, whose immediate focus revolves around economic upliftment from the, hopefully temporary, recession [Cohen, 2000].

The model described in this article (LORAX 2.0) has been constructed to provide a co-evolved dynamic systems model that is representative of the socially and spatially heterogeneous nature of South African development [Norgaard, 1994]. This platform facilitates the assessment of the long-term consequences of current South African development, and provides a platform on which to test likely government interventions for their desirability and effectiveness.

2. NATIONAL DEVELOPMENT

The philosophical approach used in the construction of a dynamic systems model of national development was based on that used by the Club of Rome in the construction the World3 model [Meadows *et al*., 1972]. Annual time-series data were collated from various sources for 127 variables of social-economic development and environmental sectors. Monetary data were corrected for inflation and standardised to 1999 US$ equivalents. The relationships between these variables were quantified mathematically, using regression analyses where necessary, and modelled in Stella 5.1.1 (High Performance Systems Inc., Hanover).

The final integrated model of national development (LORAX 1.0, see website for download: www.up.ac.za/academic/centre-environmental-studies/Lorax.html) was assessed on its ability to track historical development patterns. LORAX 1.0 was used to 1) explore the consequences of continuing along the existing path of South African development, 2) the ability of potential intervention options to delineate a more sustainable future and their secondary outcomes in non-target sectors, and to 3) assess the minimum requirements for generating a sustainable future for South Africa [Erasmus and van Jaarsveld, 2002]. The main conclusion derived from this exploratory exercise was that there are no silver bullet solutions to South Africa's development misfortunes, but rather that an integrated set of policies, targeting different sectors, are more likely to lead to sustainable development through their synergistic interactions.

3. LOCAL DEVELOPMENT

The developmental trends observed at the national level are the emergent behaviours resulting from the collective actions and interactions between smaller scale (municipal) units. These constituent components of national development resemble an ensemble of checks and balances of sustainability, where the sustainability of one district may be achieved at a 'sustainability cost' to another district [Patten, 1997; Eder and Naradoslawsky, 1999]. Such a district may, for example, provide an essential service or resource to a district that is not self-sufficient.

It is evident from these heterogeneous system properties at a finer scale that no single set of policies will adequately address the development issues for all districts. Although the implementation of such policies may deliver positive results for some districts, they may be counter-productive in other districts. Whether a policy should be implemented within a magisterial district should therefore depend on its appropriateness to the state of development in that particular district. It is the sum of local actions within districts, as well as the interactions between the districts, that collectively result in the emergent behaviour of national development.

In order to adequately explore sustainability in South Africa spatial heterogeneity between districts need to be embodied in the national analyses. Although each district is a part of the country (and of national economic, social and environmental sectors), they form whole individual units, constituted of environmental, economic and social parts, and can therefore be classified as holons with double functions [Allen and Starr, 1982]. In order to analyse these holons individually, without compromising their natural dependence, or their national context, an object oriented, multi-agent platform - Cormas [Bousquet *et al.*, 1998], see website for download: cormas.cirad.fr/ - was used. This platform allows the treatment of each individual district as an individual object, while facilitating resource exchanges with neighbouring districts. The visualisation interface of Cormas allows the initialisation of the individual districts as spatial entities with reference to their surroundings (neighbouring districts), including their extensive neighbourhood (national framework).

3.1 Development in municipal districts

The modelling of municipal districts presented seemingly insurmountable hurdles, since time-series data at the municipal level are lacking, particularly due to the re-demarcation of magisterial districts in 2001. This means that specific relationships between variables for individual districts could not be constructed. In order to approximate development in municipal districts, the mathematical equations for the national model were rewritten into the Cormas platform (Figure 1) and, where appropriate, intercepts for linear equations were downscaled from national values to those of the districts using suitable fractional multipliers (calculated using the value of the magisterial district as a proportion of the national value, e.g. local arable area as a proportion of the national arable area). These values and the remaining values for initial states of individual municipal districts were collated from the 1996 census data and from the Conservation Planning Unit geographic information system held at the University of Pretoria.

3.2 Modelling district interactions

This baseline model allows the simultaneous analyses of individual districts as isolated units. To facilitate interactions through resource exchanges between districts during the analyses, the functions describing development for districts were subdivided into two subsets: demand and production calculations. Also, a set of agents [the exchange agents] was introduced. Each agent was associated with a particular magisterial district (Figure 1).

The first subset of equations calculates the local demand as well as the potential local supply of each resource (see Figure 2). Thereafter, the agents assess the respective states of the demand and potential supply for each resource in their own districts. Each exchange agent then requests additional resources for products in which the local demand exceeds local supply. These requests are initially made to the exchange agents from the closest (first order) neighbouring districts. If one of these neighbouring districts can supply an excess of the resource, it will undertake to do so, within its own supply limitations. Each agent will continue to contact more distant districts until either i) all of the agent's resource demands have been met or ii) until it has attempted to make arrangements for exchanges with all the magisterial districts. Once the agents have completed their exchange arrangements, the production calculations are performed to ensure that production satisfies local and regional demands as conveyed by the resource exchange agents.

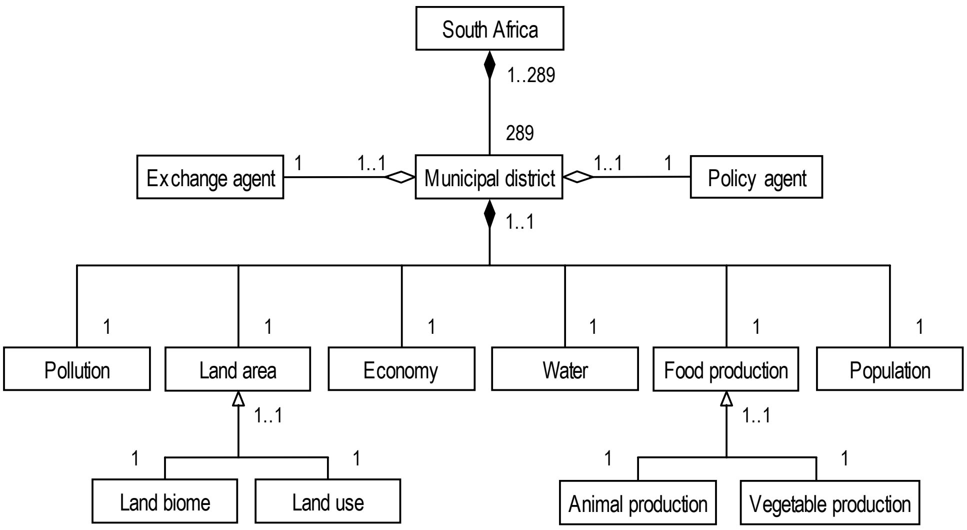

Figure 1. A simplified class diagram illustrating the structural relationships between the classes used in LORAX 2.0.

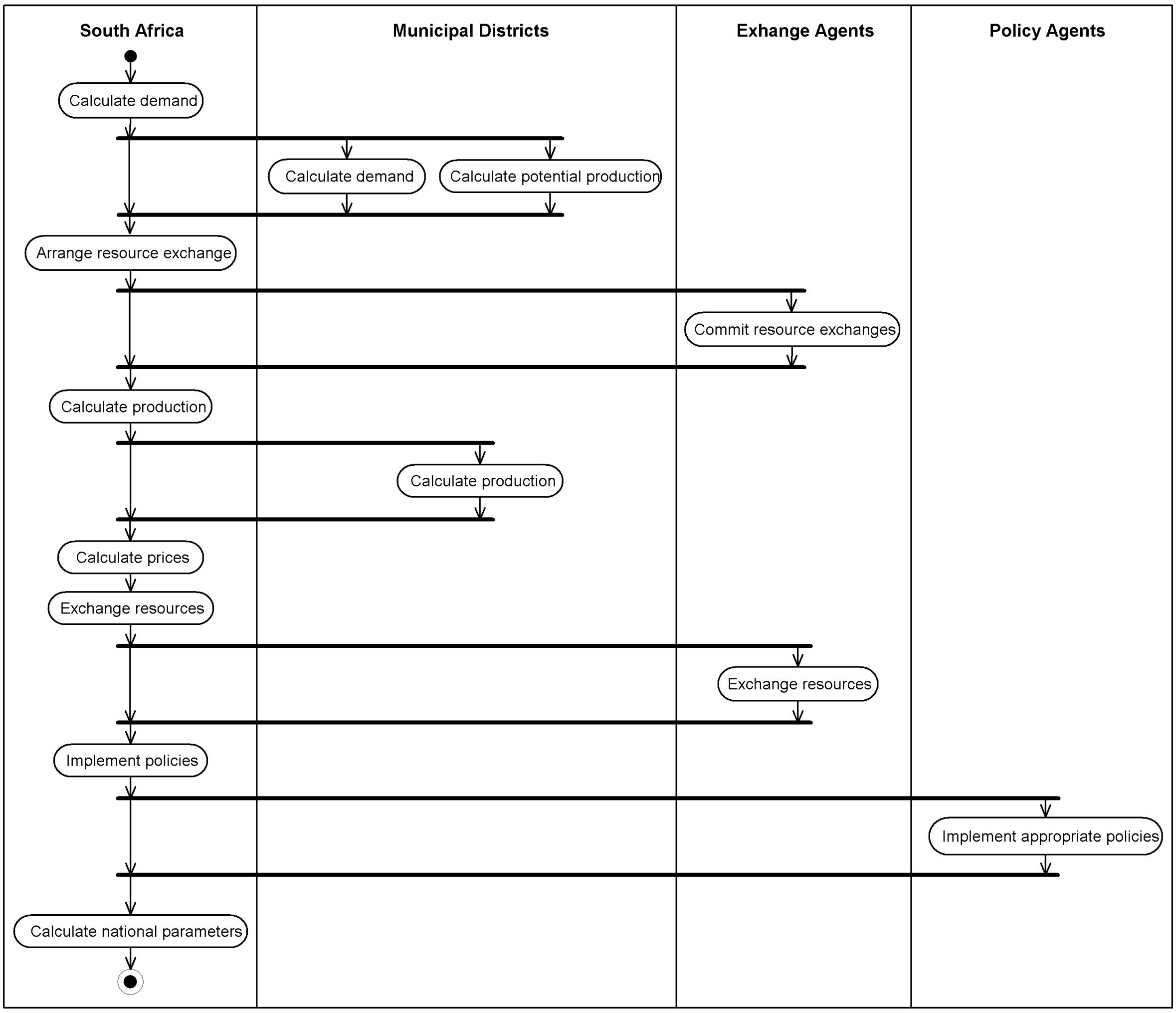

Figure 2. An activity diagram of the sequence of events constituting a single time step (one year) of the analysis at different levels of the model hierarchy. The swim lanes of the municipal districts, exchange agents and the policy agents contain synchronous activities that are performed by all districts or agents individually.

After all production functions have been calculated, the price of each resource is re-calculated from a price inflator, based on the supply of demand. The exchange agents subsequently facilitate the exchange of resources, where applicable, for their monetary value as determined during the previous step.

This procedure of resource exchange (Figure 2) is based on the assumptions that there is perfect market information, and that districts would exchange resources in a way that would minimise the distance of transport. Thus, the exchange agents balance the demand and production between districts so that a district would only produce more of a resource than demanded locally if there were a demand for additional production from another district.

4. POLICY INTERVENTION

4.1 South African government structure

Past government developmental policies can at best be described as faith based, largely because social, economic and environmental governmental departments are not properly connected at national level [O'Riordan, 1998]. Lack of communication between these departments does not facilitate the appropriate prioritisation of trade-offs among issues that cannot be simultaneously resolved

[WRR, 1995; O'Riordan, 1998]. As a consequence of this fragmented development planning, policy interventions are implemented at the national level without proper consideration for their potential impacts on non-target sectors that are governed by other departments. These asymmetrical governmental interventions, apart from having given rise to interdepartmental disputes, are unlikely to facilitate the reversal of the socio-economic crisis into which South Africa is developing [O'Riordan, 1998].

At the local level, however, many of the socio-economic development problems are much more heartfelt than at the national level [Véron, 2001], so that some municipal government bodies have managed to evolve integrated bottom-up development planning, embedded within the framework of the top-down policies passed down from national departments [O'Riordan, 1998].

4.2 Implementing intervention policies

An addition to the exchange agents, policy agents were created, with one agent allocated to each municipal district. A set of likely policy interventions was formulated and imposed on the Cormas platform. A condition was associated with each of these interventions, so that a policy will only be implemented when this conditional test is complied with (e.g. IF {GDP per capita < $200} THEN {provide a basic income}). At the onset of a simulation the user can select, from the pool of policies, one or more policies to be implemented during a run, and may adjust the conditional values for the implementation of these policies.

After each production step, the policy agents are used to test the applicability of each selected policy intervention by calculating the conditional values for economic, social and environmental variables (see Figure 2). When a conditional test is complied with for a particular intervention, the agent adjusts either the functional relationships in the model or the value of state variables necessary to implement that development policy. Such adjustments will continue to be implemented until the conditional values no longer apply.

5. CONCLUSIONS

The approach used here for the construction of the spatially explicit version of LORAX 2.0 provides a platform for analysing South African development within the framework of a complex and co-evolved society. The model can be improved over time to more closely resemble the South African reality. However, it is envisioned that LORAX will serve as a decision support tool for decision makers. LORAX can be used to test and assess various possible policy intervention strategies for addressing social-, economic- and environmental problems. The advantage of this modelling-prior-to-implementation approach is that unexpected and non-desirable consequences in non-target sectors can be detected and prevented by selecting less risky developmental pathways. The practical and predictive value of the model should however not be overstated, without proper verification of model accuracy. Pending such verification, LORAX 2.0 does not provide a perfect replica of South African development, but we consider it a useful start towards the development of a modelling framework that can inform development decision making in the future. LORAX is presently in an α-version format, requires rigorous verification, validation and further development prior to its use for exploring spatial patterns of development and policy interventions.

6. ACKNOWLEDGEMENTS

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