

Demographic and regional economic modeling using stochastic allocation in the City of Johannesburg

Christoffel J Venter*

University of Pretoria, Pretoria, 0002, South Africa

Tel. +27-12-420-2184

Fax +27-12-362-5218

Email: christo.venter@up.ac.za

Theuns Lamprecht

CSIR Built Environment, PO Box 395, Pretoria, 0001, South Africa

Tel. +27-12-841-2452

Fax +27-12-841-4054

Email: tlamprecht@csir.co.za

Willem Badenhorst

Independent Consultant, Pretoria, South Africa

Email: wbadenhorst@mweb.co.za

** corresponding author*

Word Count:	Body =	5,335 words
	7 figures and tables x 250 =	<u>1,750 words</u>
	Total =	7,085 words

Paper resubmitted for presentation and publication

15 November 2005

85th TRB Annual Meeting, 2006

Response to Call for Papers: ADB40C

Demographic and regional economic modeling using stochastic allocation in the City of Johannesburg

ABSTRACT

The paper describes a method for the modelling of demographic and economic change at a spatially disaggregate level that is compatible with the requirements of a conventional transport model. The method was developed and tested in the City of Johannesburg, South Africa, as part of a scenario planning exercise to assess potential land use and transport interventions. The procedure does not model behavioural processes explicitly, but incorporates the factors believed to influence the development of residential and non-residential land uses in a multi-criteria analysis framework, within the constraints of land availability and the guiding effects of government policy. Allocation occurs in discrete time-steps, allowing the dynamic evolution of outcomes to be modelled in a non-equilibrium framework. It operates in connected mode with the transport model, taking accessibility changes as input into subsequent land use allocations. It employs Monte Carlo simulation to approximate randomness in the location decision outcome, thus providing some sense of the variability of outcomes that may occur consistent with base year conditions, regional growth estimates, and a set of allocation criteria. The method is illustrated for the City of Johannesburg over a thirty-year planning horizon, and its particular strengths for application in a developing society are discussed.

Demographic and regional economic modeling using stochastic allocation in the City of Johannesburg

INTRODUCTION

Integrated models of urban land use and transport require forecasts of demographic and economic change at the zonal level, on which estimates of future travel demand and transport system performance can be based. In best practice models, the spatial allocation of demographic and economic changes occurs simultaneously with the estimation of travel, recognising the interdependence of land use and travel decisions at all levels of the urban activity system. Alternatively land use and travel can be determined iteratively, by linking land use allocation and travel demand models in a “connected” but not “fully integrated” manner (see (1)). An advantage of the “connected” approach, where fully integrated models are not yet available, is that it builds directly on existing transport models and expertise – an issue of some concern in middle and low income countries where resources for planning are strained.

The paper describes the process developed in the City of Johannesburg, South Africa, to allocate exogenously obtained regional demographic and economic forecasts to the transport zone level, in order to generate spatially disaggregated inputs to the (connected) transport model. The procedure does not attempt to model explicitly the complexity of decisions made by the multiple agents who contribute to change in the urban environment. In the local context, some of the current issues which add complexity to the effort to model land use and demographic change include:

- Potentially fast demographic change due to migration and especially changing mortality patterns. The likely impacts of the AIDS epidemic are highly uncertain at this stage; one study indicates that South Africa’s population as a whole will *decline* after 2007 as a result of deaths due to AIDS, especially among women of child bearing age (2).
- Associated uncertainty around the impacts of AIDS on economic growth, household welfare and incomes. For instance, the extent to which higher mortality among low-income earners will increase welfare dependency (and possibly increase the travel needs of caregivers) is unknown.
- Relatively significant state intervention in the housing market, through state directed programmes for providing subsidised basic housing for low-income families. There is also strong government intention to more pro-actively shape urban form and transport, in order to redress social imbalances of the past and promote more sustainable growth, using instruments such as urban growth boundaries and incentivising investment in priority nodes and corridors.
- The informal sector is often a significant creator of employment, especially with respect to informal trade, household services, and transport. Locationally this sector probably responds to different economic stimuli than the formal sector (on which current land use models focus).
- Significant human resource and institutional constraints impinging on local governments’ ability to design and implement effective policies.

In light of these complexities, it is felt that value can be derived from employing a land use modelling approach that is flexible and less costly to develop, even while work is ongoing to calibrate and validate more behaviourally complex models for local conditions. The procedure described here creates a platform for compiling a joint

understanding of the likely combined impacts of the above-mentioned factors, from the domain knowledge of a variety of actual roleplayers familiar with local conditions and processes. It provides a way of integrating this knowledge within the constraints of feasibility and consistency on the regional/metropolitan scale. In addition, it explicitly recognises uncertainty around the outcomes by employing a stochastic simulation procedure to generate a range of potential outcomes for further analysis. This adds complexity to the output, but could (at least in theory) assist in developing land use/transport strategies that are robust across a range of uncertain futures, rather than a single “master plan” that is inflexible and soon outdated.

By way of providing background the paper briefly locates the Johannesburg approach within the context of urban models. The demographic and economic allocation procedure is then described in more detail, together with its salient features. Then follows a brief example of its application to date in Johannesburg, and lastly some conclusions.

BACKGROUND

Land use-transport modelling approaches

A useful typology of the land use component of urban models as provided by Miller et al (3) and adapted by Johnston et al (4) is shown in Figure 1. The majority of operational approaches, in the US and elsewhere, fall into the Stand Alone category, where they provide land use forecasts exogenous to a transport model, employing a combination of judgment and simple trend analysis techniques (4). As advances in computing power (including Geographic Information Systems (GIS)), data availability, and theoretical tractability occur, planning agencies with higher modelling needs can migrate to more sophisticated land use models that are either connected or fully integrated with transport demand models. The range of options is quite large in terms of theoretical basis, software availability, and output features.

Rule-based models do not use choice or other statistical models to simulate individual behaviour, and are not strictly calibrated using historical data. Their simplicity and ease of implementation make them highly suitable as a starter approach, from where planning agencies can graduate to more complex models as users gain experience (4). Notable models in this genre include UPlan (4), and What If? (5). A feature these models, and others like the California Urban Futures urban growth models (CUF and CUF-2 (6, 7, 8)), have in common is their reliance on the strengths of a GIS to identify developable land and to estimate its suitability for development from a variety of spatial

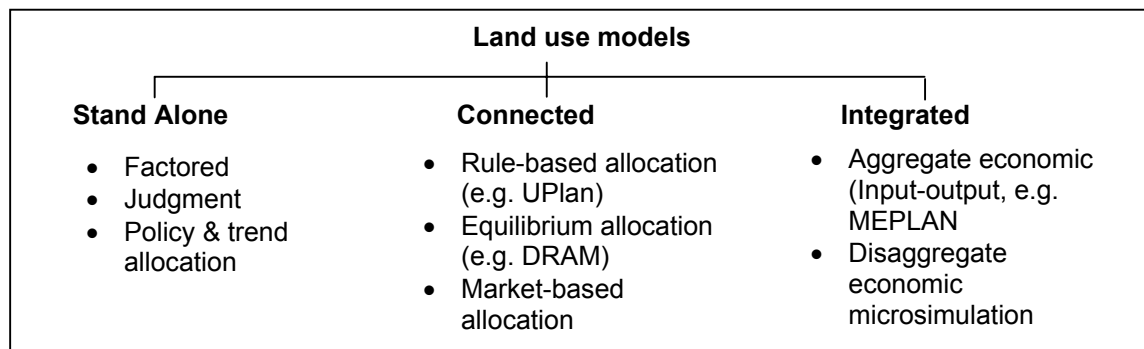


FIGURE 1 Typology of land use component of land use-transport models

variables.

A particular strength of a GIS that makes it attractive for supporting land use modelling is its ability to manage, store, and display large amounts of spatial data. GIS's are available in the planning departments of many cities, including the larger cities of medium-income countries. GIS practitioners in these agencies are increasingly moving towards using the data for more sophisticated analysis (9), such as the use of overlaying techniques to integrate multiple layers of information. In fact, available software that automates overlaying and calculation processes makes it highly suitable for conducting multiple criteria-type analyses (MCA), such as that explained in this paper.

The current model appears to be most similar to UPlan (4), which uses a number of "attraction grids" and "exclusion grids" to identify grid cells to which new development can be allocated. The attractiveness of cells is typically estimated from their proximity to existing urban areas and transportation facilities such as freeway ramps and passenger rail stations. Cells in areas where development cannot occur, such as rivers, public open space, and existing built-out areas, are excluded from development. The model allocates future development deterministically proceeding from the most attractive cells to less attractive cells, until all units of projected land consumption are allocated. This is done for all land use categories except low-density residential, which is randomly allocated throughout the available rural areas. UPlan has been implemented in a variety of planning applications in the United States.

Land use-transport modelling in Johannesburg

The allocation procedure was developed as part of a scenario development exercise undertaken by the City of Johannesburg to evaluate the performance of alternative transport and land use interventions for a thirty-year horizon. Implicit was the need not only to test various public transport and road infrastructure provision strategies, but also to test the feasibility of the city's policy-driven land use densification strategy from a mobility and accessibility point of view.

The City of Johannesburg is South Africa's largest local economy, contributing 17% of national production (10). The metropolitan area covers 1,300 square kilometres, with a 2001 population of about 2.7 million. The city houses most of the country's corporate headquarters, having experienced particularly fast growth in the financial services and trade sectors in recent years. Land use patterns reflect historically high levels of social inequality, with higher density, lower income neighbourhoods located far away from the more dispersed higher income suburbs and employment nodes in the north. The high cost of access to the (formal) economy contributes to poverty (about a quarter of residents live below the poverty line), and significant informal sector activity (10% of all jobs are estimated to be in the informal sector (10)).

The land use-transport modelling context within the City of Johannesburg is not unique compared to other cities within South Africa where the land use and transportation models are "connected" rather than "integrated". The land use models are often developed within spreadsheet-based packages, while transport models are most typically implemented using the Emme/2 software package.

Figure 2 illustrates the process followed in transforming the regional growth trends into disaggregate inputs usable by the transport model. The land use model is dependent on current data on population, job opportunities, economic activity, and land use. Future growth in population and economic activity is estimated exogenously for the region, and converted to physical units that can be allocated on a spatial grid – in this case dwellings and floor space in the office, retail, and commercial/industrial categories –

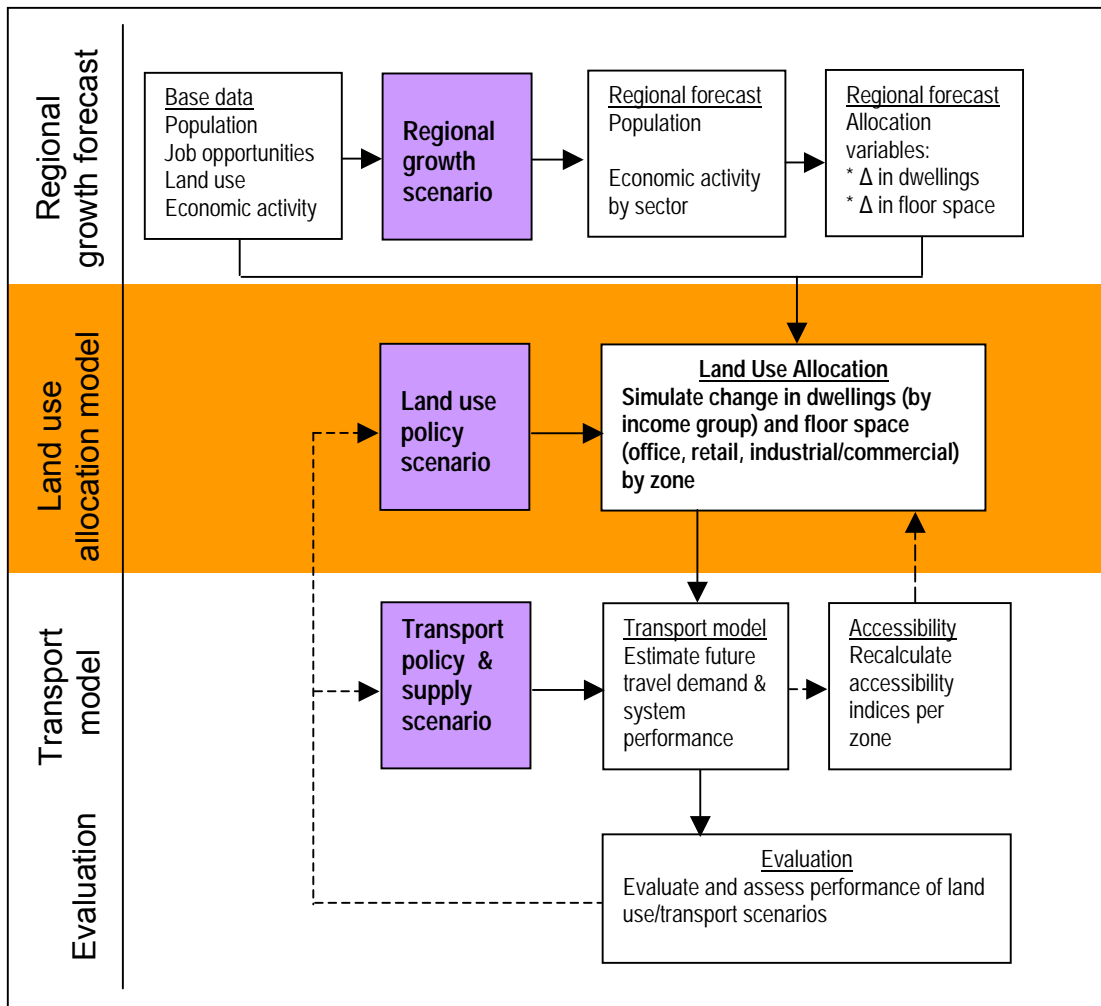


FIGURE 2 Overall land use-transport modelling framework in the City of Johannesburg

using known (and assumed constant) relationships between population, households, and dwellings (in several income categories), and between sectoral economic activity and floor space consumption. The stochastic allocation procedure then allocates dwellings and floor space on a disaggregate level, guided by a chosen land use policy and supply scenario, and aggregates the output to the transport zone level where it serves as input into the transport model. The land use allocation variables are then used in the trip generation phase of the transport model to determine future transport demand for a particular transport supply scenario of interest.

Feedback from the transport model to the land use model occurs during the allocation procedure itself (using accessibility indices as described below), and also during scenario testing where transport system performance can guide the refinement and development of alternative land use/transport scenarios for further testing.

DESCRIPTION OF LAND USE ALLOCATION MODEL

The main purpose of the demographic and economic allocation model is to “disaggregate” exogenously derived population and land use change forecasts for the region, by allocating them to the transport zone level.

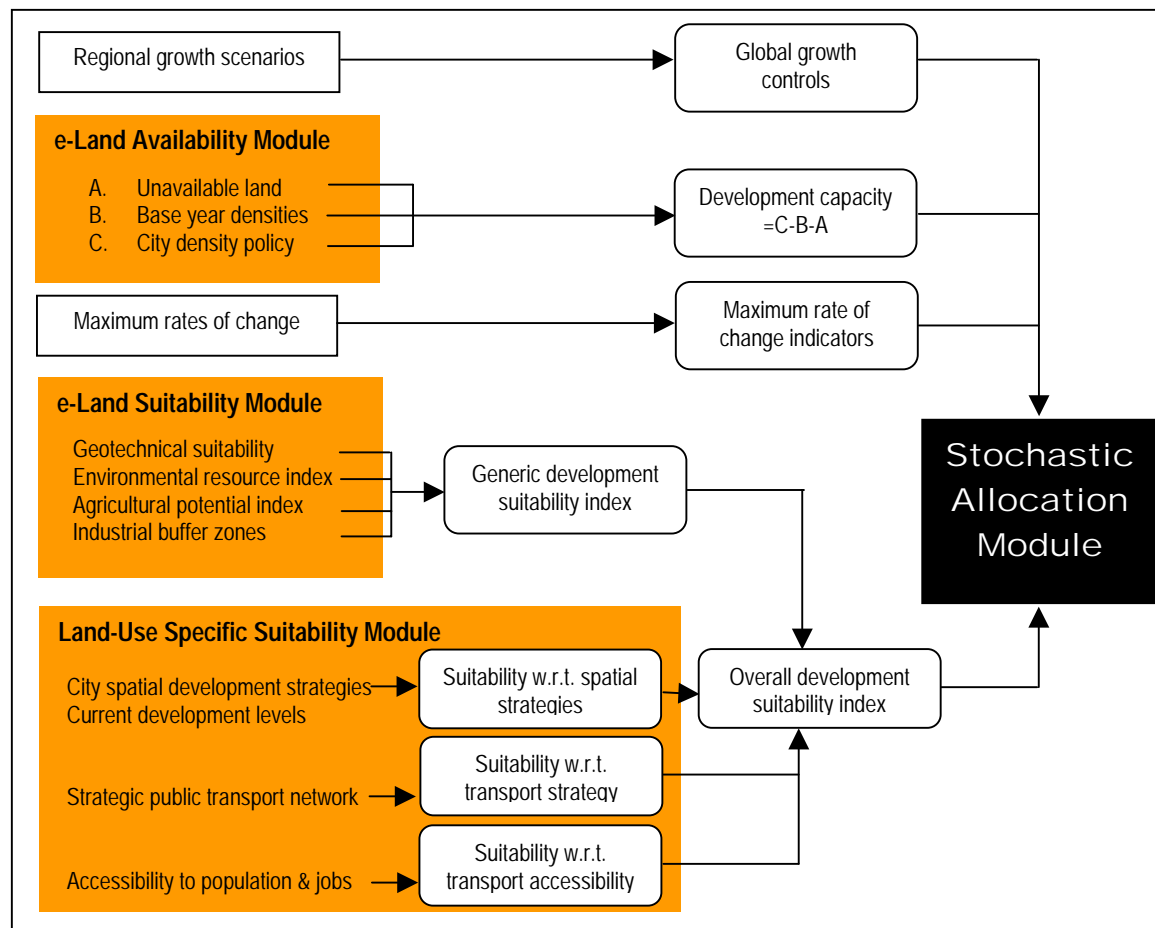


FIGURE 3 Main components and information flows of allocation procedure

The engine of the model revolves around estimating the likelihood of development of a certain type occurring within a zone, and simulating the occurrence of such development over time, consistent with both overall growth trends and local development constraints.

The model has five components, as shown in Figure 3. These are:

1. **Global growth controls:** The total change in the number of dwellings (per income category) and the amount of floor space by development type (retail, office, commercial and industrial) in the city between the base and horizon years is taken as input to the model, and used as overall controls to the allocation process. If credible forecasts are available at a finer level of disaggregation (for instance by subregion within the city) these could provide additional controls.

2. **Development capacity:** The development capacity of each land parcel expresses its absolute potential for future development. This is calculated using:

- The base year level of development in each parcel;
- The maximum amount of development allowable in each parcel under prevailing zoning and density scenarios, as if the entire parcel were available for development; and

- The extent of non-negotiable unavailable land, including protected nature areas, waterbodies, institutional enclosures, cemeteries and monuments, and areas with steep slopes.

The development capacity is calculated for each parcel and development type by subtracting the base year development and unavailable land from the maximum development allowed.

3. Maximum rate of change indicators: The rate at which development can occur in an area is in practice limited by the various roleplayers' capacity to plan, design, fund, construct, and occupy new buildings, as well as institutional capacity to approve rights and building plans and to deliver public infrastructure. The maximum rate of change indicator captures this limitation by acting as an upper boundary to the amount of new development of each type that can become available in a parcel within a given time period. Areas with extensive brown-fields developments, for instance, can be expected to have a lower rate of change than areas with comparable greenfields developments, due to the more extensive stakeholder involvement and higher costs typically associated with subdivision and infill development. The maximum rate of change indicator can thus be expected to depend on the extent and nature of existing development in a parcel, the characteristics of the overall delivery process, and any fast tracking provided by authorities for specific priority areas.

Objective information on rate of change limits requires time series data on development that could partly be sourced from a local government's development application database, where available. However this would have to be interpreted with care to obtain maximum rather than historical rates of change, which are not necessarily the same. In the absence of time series data, it may be more appropriate to develop rate of change limits that incorporate both objective indicators and the subjective domain knowledge of both private and public sector professionals. The value of this approach was demonstrated in the case of Johannesburg, as is discussed below.

4. Development suitability indices: In contrast to the previous three components, which effectively control the maximum amount of development of a certain type that can occur in a given parcel over a given time period, the development suitability index expresses the likelihood of development *actually* taking place. Indices are calculated for each parcel by means of a multi-criteria analysis (MCA), using criteria that are considered to determine suitable locations for specific land uses. While the MCA is a completely general approach allowing indices to be structured as desired, in this application two broad types of suitability are considered:

- *Generic suitability criteria* reflecting a parcel's general suitability for urban development, and
- *Land use specific criteria* reflecting a parcel's suitability for each specific land use (residential, office, retail, and commercial/industrial).

Generic criteria refer mainly to environmental constraints, including geotechnical weakness, industrial buffer areas, and environmentally sensitive areas, which contribute towards lowering the suitability index for a parcel. They apply to all land use types.

Land use specific criteria are assessed separately for each land use type, and refer to three types of development factors, namely current development levels, accessibility, and land use/transport policies:

- *Existing (base year) levels of development* of a given type in a zone are taken as an indication of the attractiveness of the zone for further development. It is, in effect, a proxy for the many (mostly qualitative) characteristics of an area that affect its desirability for real estate development, but on which data may not exist. This criterion would be stronger for office than for industrial development, for instance, as office development tends to benefit more from economies of agglomeration.
- The benefits of access to other activities and of efficient transport systems are captured through an *accessibility index*, which is calculated for each zone based on observed or modelled (equilibrium) travel times to/from the zone, weighted by the importance of each destination zone. The accessibility index should be continuously updated as new development is simulated, using modelled travel demand and transport costs determined in the transport model. This allows the effects of increased congestion resulting from new development to be captured correctly. It implies the need for full feedback between the land use and transport components of the overall model. Important to note here is that accessibility should be defined in terms of the functional economic interaction space, which could be larger than the metropolitan area, in order to capture the structuring role of economic activity outside the area. For instance a node on the edge of the modelled area could have high attractiveness for future investment due to its proximity to economic nodes and/or labour in adjoining cities – the accessibility index should reflect this attractiveness.
- The impacts of any *land use/transport planning policies and control instruments* are captured through indices indicating the “desirability” of development of a certain type occurring in a parcel, from government’s point of view. This requires interpretation of the often qualitative statements contained in planning documents on the extent, type, and density of development that is considered desirable in specific areas to reach some spatial, economic, or transport development goals. Examples of policies that can be evaluated in this way include urban growth boundaries, prioritisation of certain investment nodes, and densification around priority public transport routes. Individual land parcels are given a score reflecting their location vis-à-vis any number of these spatial policies.

The selection of the criteria to include in the suitability assessment is in line with conventional thinking and empirical findings on factors affecting the choices made by agents in the land development process. For instance, work done during the development of UrbanSim, a comprehensive urban model, identified similar variables as pertinent to the land development process: current development levels, policy constraints, proximity to existing development, and regional access to population (11, 12). These variables are included in UrbanSim’s real estate development model. The role of accessibility in the real estate development decision is widely accepted, even though recent evidence suggests that accessibility plays a somewhat smaller role in the location choices of households than previously believed (e.g. 13).

The calculation of suitability is done at the parcel level, and aggregated up to the zonal level as required by the allocation procedure. It has been implemented in a GIS framework, within a custom-made application called e-Land that was originally developed for suitability analysis for low-income housing in South African cities. e-Land has an MCA module that allows the user to calculate a single suitability index (or one for

each development type) for a parcel or zone using user-specified weights for each of the component criteria. The weights reflect the relative importance of each criterion in determining overall suitability. They can be based on a combination of theoretical/empirical evidence on factors affecting development patterns in the area, and the subjective domain knowledge of experts familiar with local development processes. Some amount of calibration can be achieved with reference to base year or historic development patterns.

5. Stochastic allocation module: The allocation of new dwellings and floor space (by development type) is done using a Monte Carlo simulation procedure that mimics the dynamic nature of the land development process. The simulation proceeds in discrete user-specified time steps (such as year by year). In each time step the additional number of dwellings and floor space is allocated stochastically, according to the suitability index for each parcel. The suitability index is normalised to a value between zero and one, so that it can be interpreted as a likelihood of development occurring at a particular location at a particular point in time.

The allocation to a specific land parcel proceeds until any of the following limits are reached:

- the maximum rate of change allowed for a specific time step (year) is reached, or
- the maximum development density for the parcel as specified by the development capacity for that land use is reached, or
- the final time step in the analysis is reached.

If the total amount of new development is less than the capacity available in the base year (which is most likely the case), the stochastic allocation procedure will produce a different development pattern at the horizon year every time it is run. This is entirely in keeping with the probabilistic nature of forecasting an uncertain future outcome. In this case, the simulation can be repeated a number of times, to provide a sense of both the expected or “most likely” land use pattern to emerge at the horizon year, and the variation across outcomes that are feasible and consistent with the constraints. Methods for analysing the variation across outcomes, in relation to for instance the robustness of the land use/transport strategies being tested, are currently being developed.

FEATURES OF THE LAND USE ALLOCATION APPROACH

Salient features of the Johannesburg approach include the following:

- The approach is in essence data intensive. However, it depends on spatial information that is generally available in the GIS section of large cities, including layers on base year land use, non-available and environmentally sensitive land, and transport networks. In the case of Johannesburg the existence of high quality GIS data made the application of the allocation approach eminently possible.
- Spatial aggregation up to the transport zone level only occurs during the simulation step. The calculation of development potential and suitability is done at the individual parcel level, thus preserving a high level of spatial detail during the analysis.
- While the procedure has thus far been described in terms of the spatial allocation of *new* land use in a region, the method is equally capable of dealing with negative growth in zones. Negative growth can be accommodated in one of two ways:

- Dedensification occurring as a result of *government actions* to alleviate overpopulation problems in certain areas (a not uncommon issue in developing countries) is captured by specifying a residential development capacity that is lower than the base year density in a zone. The algorithm automatically removes the excess households from such a zone and reallocates them elsewhere.
- Decline in a zone as a result of *market forces* (such as CBD decline due to suburbanisation of jobs and population) can be captured by specifying a “threshold” suitability level, below which the algorithm removes households or occupied floor space from a zone and adds it to the stock to be allocated elsewhere in the region. This feature has not yet been implemented.
- The model is capable of dealing with price signals only in an approximate manner, to the extent that data on (current or estimated future) land values can be incorporated into the suitability index, and given different weights depending on the income class considered. For instance, land values may carry a higher weight in calculating the suitability index for low income housing than for high income housing. However the model lacks the theoretical basis to endogenously estimate price changes.
- Traditional end-state scenario modelling has been criticised for not paying enough attention to the “dynamic pattern of events that brings a particular scenario about” (e.g. (14)). The allocation procedure is capable of capturing some of the dynamic aspects of the land development process explicitly. Dynamic effects occur when the process itself determines the outcome at a certain year, and it is impossible to arrive at that outcome without considering the process. In the model dynamic effects can occur if the criteria governing the allocation are allowed to change from time step to time step. This can happen, for instance, if the accessibility index is updated conditional on the previous step’s land use allocation and its resultant travel cost impacts. Dynamic effects can also be captured by changing the maximum rate of change or development suitability criteria at intermediate years of the simulation. The outcome can be enlightening in terms of understanding the impacts of the *timing*, in addition to the nature and extent, of government intervention in the land use and transport markets.
- Although they were developed independently, the present approach is similar to the UPlan model (4) in terms of its model structure and data requirements. Similar variables are or can be used for estimation of development suitability, including proximity to existing development, transport accessibility (used by UPlan in Sacramento), and land use plans. What appears to be new in the Johannesburg approach is its use of a stochastic allocation procedure, rather than the usual deterministic one, in actually allocating new development to zones. An indication of the relative value obtained from this refinement is provided in the next section.
- The method allows for some measure of subjective input during quantification of the maximum rate of change indicators and the weights attached to the suitability criteria. These inputs affect the modelled outcomes, and naturally have to be carefully managed within the structured procedure described here. There may for instance be a tendency among officials promoting government intervention through land use/transport planning policies and instruments to overestimate the importance of these policies in guiding private sector investment decisions. Their inputs should be balanced by those of experts from the private sector, perhaps by employing a Delphi or similar technique. Yet despite its obvious pitfalls, the use of subjective criteria has in the present case been found to be advantageous for the following reasons:
 - It captures the domain knowledge of professionals who may have very good insight into the combined effects of some of the complexities found in developing societies, potentially introducing a level of realism not attainable with

more behavioural models at their current state of development. It is partly for this reason that Delphi techniques and expert panels are increasingly receiving attention as land use forecasting tools (15).

○ The process of obtaining subjective inputs provides a platform for institutional strengthening and communication among land use and transport planners – an issue of particular concern in South Africa at the moment. Thus, rather than operating in the much criticised “black box” mode, the land use forecasting step becomes a transparent exercise for building a common understanding of problems and of “the way the world works”.

ILLUSTRATIVE APPLICATION: CITY OF JOHANNESBURG

The allocation model’s application to the City of Johannesburg provides an illustration of its capabilities. Base year (2001) land use and demographic data were obtained from recent surveys and census information. Regional growth estimates for population (by income group), economic activity (by economic sector), and household income were exogenously supplied for various growth scenarios for the horizon years 2010, 2020 and 2030, and converted into an overall demand for dwellings (for subsidised and unsubsidised housing) and floor space demand (for office, retail, and industrial/commercial) using historically derived conversion factors.

Development capacity was determined from maximum allowable densities that are being considered for implementation by the City Council to promote urban densification and infill development, especially near public transport nodes and corridors. Maximum rate of change indicators were developed by the project team, and refined based on initial model outputs. Table 1 shows as an illustration the rate of change indicators used for residential development.

The development suitability indices were compiled at the land parcel level from several data sources.

Generic environmental constraints included land with agricultural, ecological, heritage, or social sensitivity. The accessibility indicator was calculated for each zone, based on travel times by road (car and bus modes) to all other zones, weighted by the employment and population figures of each destination zone. The indicator was recalculated in each iteration to capture the dual effects of a parcel’s deteriorating access due to growing congestion, and improving attractiveness due to the location of other development nearby (if any).

TABLE 1 Initial maximum rate of change indicators: Residential development

Nature of development area	Residential development type	Maximum rate of change (new dwellings per hectare per year)
Greenfields	Subsidised housing	40
	Non-subsidised housing	10
Brownfields (primarily residential zoning)	Subsidised and non-subsidised housing	Between 0.2 and 1.0, depending on average income of households in zone
Brownfields (mixed use developments)	Node with primarily retail or office zoning	0.5
	Node with primarily industrial/commercial zoning	zero

Non-available land was identified as described above, and excluded from development. Calculation of suitability in terms of government land use/transport policies was based on a parcel's location in relation to the City's published spatial development strategies and nodal programmes, as well as its location in relation to the City's strategic public transport network that is being targeted for densification.

The components of the suitability assessment were weighted in the MCA procedure using weights that were developed by the researchers in consultation with City officials, and reflect a combination of empirical evidence from the literature and local knowledge. The allocation procedure was run in five-year time steps. In each year it simulated dwelling allocation one dwelling at a time, and economic land uses in increments of 100 square meters of floor space.

Two sources of variation in the allocated land use are the randomness of the Monte Carlo procedure used to allocate future dwellings/floor space across zones, and the suitability indices that change from time step to time step. Figure 4 shows the extent of the resultant variation in allocated dwellings/floor space across simulation runs, expressed as a percentage of the average base year dwellings/floor space, for two land use types. Although in absolute terms the marginal allocation per cell can vary substantially across simulations, in relative terms the variation tends to be quite small compared to the existing land use levels. Across five simulations, the allocation per zone varied between 3 and 4% on average (for non-subsidised housing) and between 1 and 2% (for retail). Interesting is the upward trends in variation that are evident over time, implying that the marginal allocation to a zone tends to either decrease or increase over time. This indicates the positive feedback effect of accessibility on a zone's attractiveness to development. Zones that receive higher allocations in early years are more likely to attract additional development in future years. The feedback effect appears to be stronger for retail than for housing, which is consistent with the observable concentration of retail establishments into fewer and larger shopping malls and retail districts.

At higher levels of geography, however, the simulation variation decreases. At the level of subregions (of which there are eleven in the study area), the variation across simulations is less than 1% (Figure 5). The same increasing trend is still evident over time. At higher aggregation levels more of the zonal-level variability cancels out, leaving smaller variation across simulated outcomes. In fact, at the subregional level the cumulative allocation of new dwellings/floorspace at 2020 was almost identical across the five simulation runs.

Figure 6 illustrates the outcome of one run of the allocation procedure: it shows the suitability indices and the simulated residential land use allocation at the year 2010 for non-subsidised residential development. The allocation can be seen to match the suitability pattern relatively closely. Some housing provision is forecast in more central parts of the city (for example regions 4 and 8), but the figure illustrates the extent to which more peripheral, suburban housing provision is likely to persist.

Non-subsidised housing seems to spill over towards the north west of the city, taking up not only highly suitable but also slightly less favourable land (from a compact city policy point of view). This indicates firstly that density constraints in the highly suitable core of the city is likely to force development further outwards – a situation that merits further consideration as city officials refine their density and zoning policy. Some new housing will locate close by the strategic public transport network that is the prime contributor to the highest suitability cells in Figure 6, assuming the proper incentives are provided. However the strategic network is primarily focused on the inner areas. There

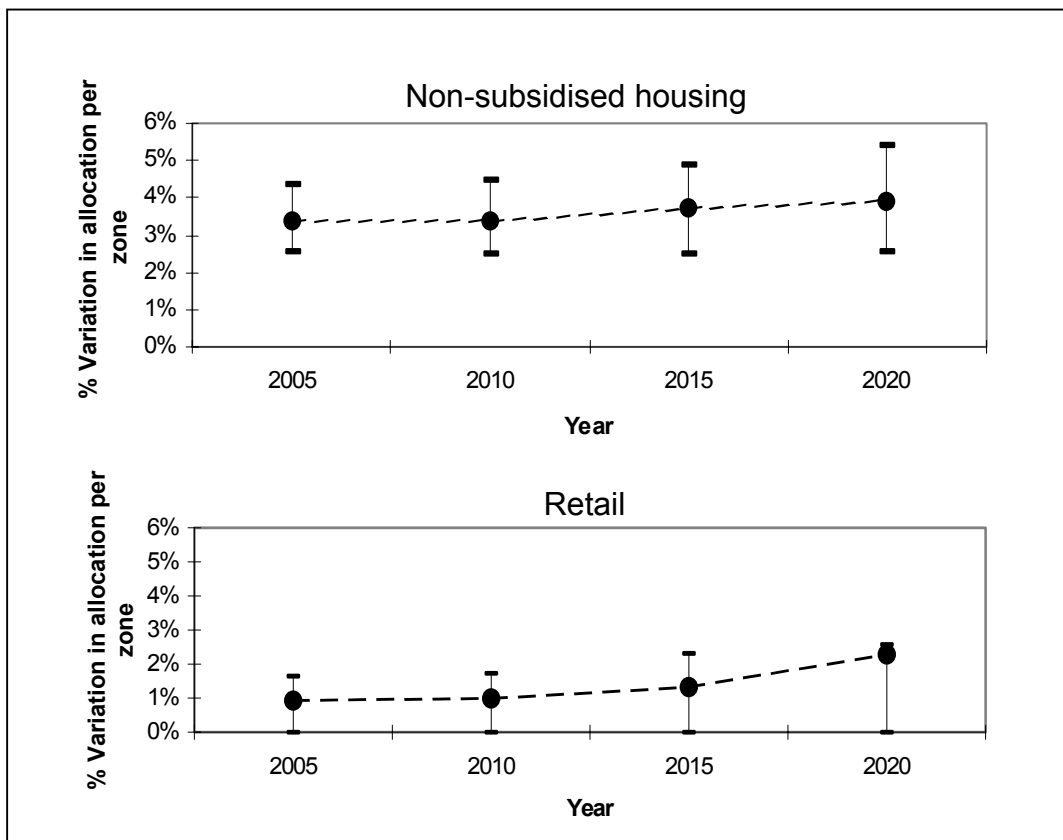


FIGURE 4 Zonal level variation in allocation results across simulation runs (average trend, 1st and 3rd quartiles shown)

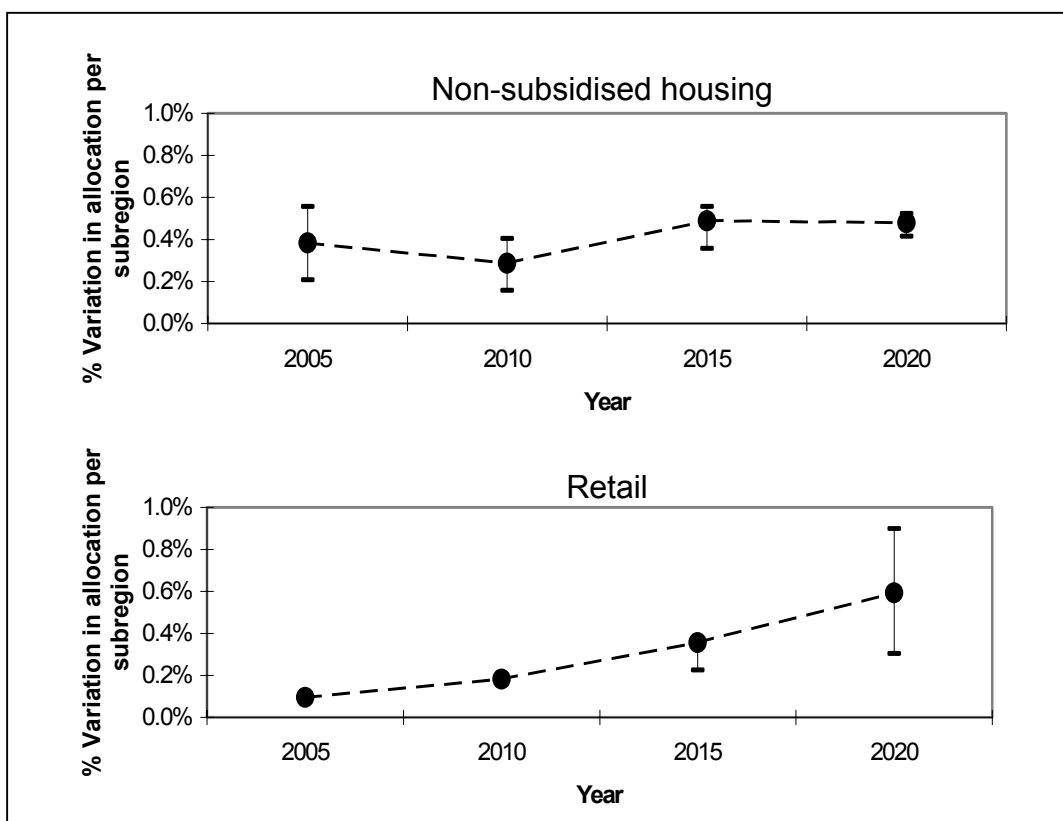


FIGURE 5 Subregional variation in allocation results across simulation runs (average trend, 1st and 3rd quartiles shown)

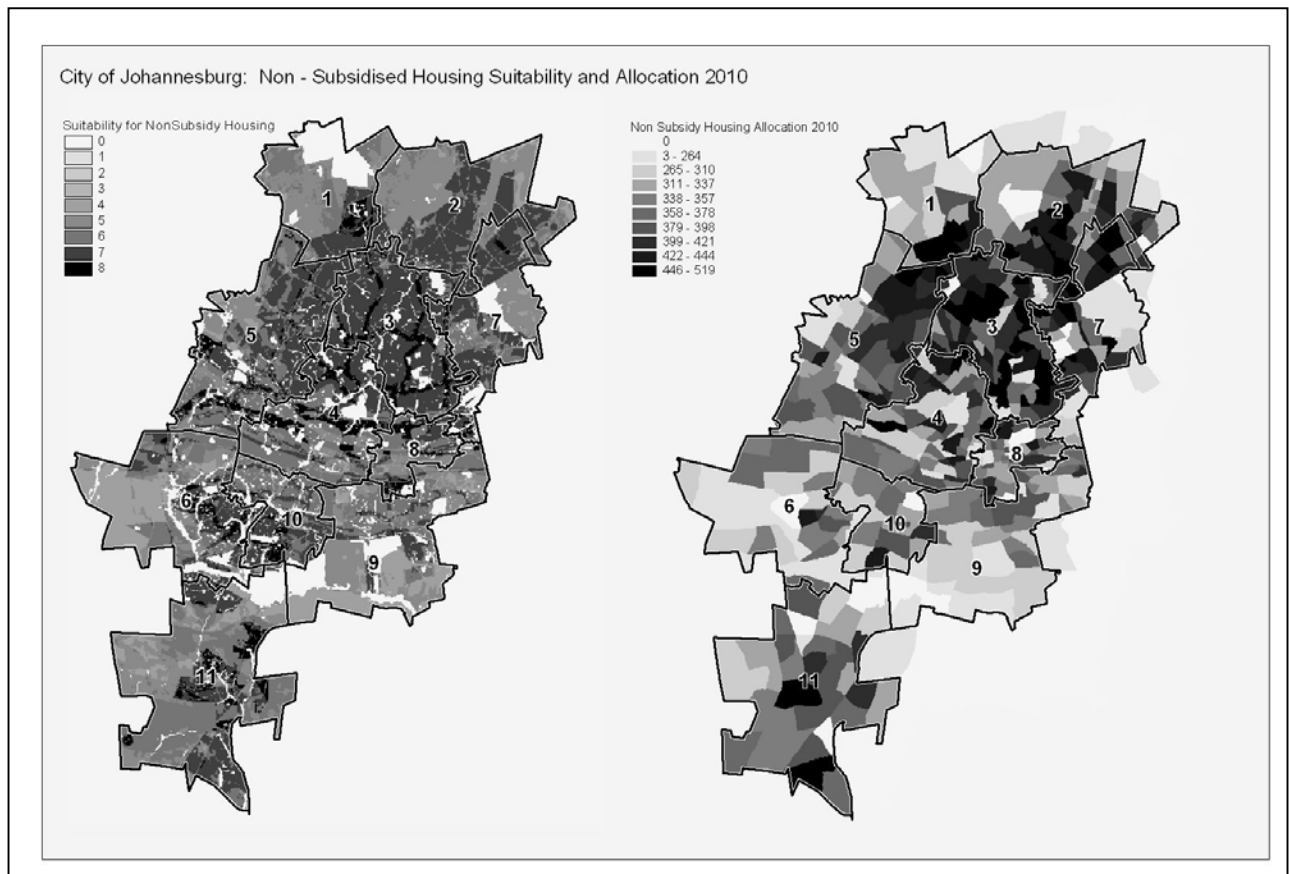


FIGURE 6 Example of suitability indices and output of allocation procedure: City of Johannesburg, for 2010

is evidently a need to think carefully about creating viable public transport, and land use patterns to support it, in the newer outer areas of the city as well.

CONCLUSIONS

The paper describes a method for modelling demographic and economic change at a disaggregate spatial level that is suitable as input to a conventional transport model. The method was developed and tested in the City of Johannesburg, South Africa, where it is used as part of a scenario planning exercise to assess future land use and transport interventions.

A strength of the method in this context is its ability to assimilate information from diverse sources, including GIS databases of existing conditions, government policies and strategies around land use and transport, and subjective input from experts on the relative contribution of these and other factors to shaping the intermediate processes and final outcomes of urban development. Operationally it is designed to be connected to a transport demand model, thus incorporating information on travel quality into the land use location model. Another strength is its ability to simulate dynamically the process of change, rather than focusing on predicting a single future state. This allows it to explicitly capture feedback effects from one time step to the next, such as the impact of changing accessibility patterns on future development.

The simulation is capable of generating a distribution of potential outcomes that are consistent with the constraints and with the factors assumed to guide decisions in the

market. Its use of a stochastic procedure for allocating development to available land produces not only a single “expected” future land use outcome, but can also give insight into the level of uncertainty or variability attached to that outcome. Application of the method in Johannesburg indicated that at the zonal level the extent of this variability for any one zone may be large in absolute terms, but smaller when considered relative to *existing* development. All of these strengths seem particularly useful in a developing society like South Africa that is subject to fast change and high uncertainty around demographic, economic, and institutional trends, insufficient knowledge of behavioural processes in (and outside) the market, and data limitations.

The model does not attempt to explicitly model the complexity of intermediate decisions taken by the multitude of actors in the urban environment. Its behavioural weakness will be most relevant when attempting to model radical changes in government policy or economic behaviour, on which insufficient theoretical or experiential information is available to guide experts and officials giving input into the model. However, the model does not require extensive calibration and was developed in a matter of months rather than years. It is perhaps a good demonstration of how vital GIS technologies can be in helping to provide fast and practical solutions to complex problems when data to establish more elaborate behavioural techniques are absent or too costly to collect.

The approach taken is that, in agreement with Timmermans (16), the main intention is to provide “some rough possible qualitative indication for wider areas, rather than a detailed quantitative assessment, of tendencies and likely impacts of land use and transport policy scenarios.” The allocation method described here explicitly provides a platform for both technical and non-technical roleplayers to engage with the issues and factors shaping the outcomes for wider areas. It thus contributes towards building the capacity of the very people whose task it is to design and implement policies and projects to achieve society’s goals.

ACKNOWLEDGMENTS

The contributions of numerous officials from the City of Johannesburg’s Department of Development Planning, Transportation and Environment to the work described here is gratefully acknowledged. The opinions contained herein are solely those of the authors.

REFERENCES

1. Hunt, J.D., D.S. Kriger, and E.J. Miller. Current Operational Urban Land-use-Transport Modeling Frameworks: A Review. *Transport Reviews*, Vol. 25, No. 3, 2005, pp.329-376.
2. South African Cities Network, *State of the Cities Report 2004*. <http://www.sacities.net/2004>. Accessed May 2005.
3. Miller, E.J., D.S. Kriger, and J.D. Hunt. *Integrated Urban Models for Simulation of Transit and Land Use Policies: Guidelines for Implementation and Use*. TCRP Report 48, TRB, National Research Council, Washington, D.C., 1999.
4. Johnston, R.A., D.R. Shabazian, and S. Gao. UPlan: A Versatile Urban Growth Model for Transportation Planning. In: *Transportation Research Record: Journal of the Transportation Research Board*, No. 1831, TRB, National Research Council, Washington, D.C., 2003, pp.202-209.
5. Klosterman, R.E. The What If? Collaborative Planning Support System. *Environment and Planning B*, Vol. 26, 1999, pp.393-408.

6. Landis, J.D. The California Urban Futures Model: A New Generation of Metropolitan Simulation Models. *Environment and Behavior B*, Vol. 21, 1994, pp.399-420.
7. Landis, J., and M. Zhang. The Second Generation of the California Urban Futures Model. Part 1: Model Logic and Theory. *Environment and Behavior B*, Vol. 25, No. 5, 1998, pp.657-666.
8. Landis, J., and M. Zhang. The Second Generation of the California Urban Futures Model. Part 2: Specification and Calibration Results of the Land-Use Change Submodel. *Environment and Behavior B*, Vol. 25, No. 5, 1998, pp.795-824.
9. Dueker, K.J., and T. Ton. Geographical Information Systems for Transport. In: *Handbook of Transport Modelling*, edited by D. Hensher and K. Button, Elsevier, 2001, p. 263.
10. Global Insight SA. *Economic Profile Overview of City of Johannesburg Metropolitan Region: October 2004 Update*. Pretoria, 2004.
11. Waddell, P. and M. Alberti. *Integrated Simulation of Real Estate Development and Land Cover Change*. Paper presented at 4th International Conference on Integrating GIS and Environmental Modelling, Banff, Alberta, Canada. 2000.
12. Waddell, P. UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *Journal of the American Planning Association*, Vol. 68, No. 3, 2002.
13. Molin, E. and H. Timmermans. *Accessibility considerations in residential choice decisions: accumulated evidence from the Benelux*. Paper presented at the Annual Transportation Research Board meeting, 2003, Washington, D.C.
14. Pearman, A.D. Scenario construction for transport planning. *Transportation Planning and Technology*, Vol. 12, 1988, pp. 73-85.
15. Federal Highway Administration. *Use of Expert Panels in Developing Land Use Forecasts, Proceedings of a Peer Exchange Sponsored by the Travel Model Improvement Program*. October 23-24, 2002. Report FHWA-EP-03-018, U.S. Department of Transportation, http://tmip.fhwa.dot.gov/clearinghouse/docs/landuse/expert_panels/panels.pdf. Accessed 28 July 2005.
16. Timmermans, H. *The Saga of Integrated Land Use-Transport Modeling: How Many More Dreams Before we Wake Up?* Presented at 10th International conference on Travel Behaviour Research, Lucerne, August 2003, page 27.