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LAND USE CHANGE MODELLING IN DEVELOPING COUNTRIES: ISSUES AND PROSPECTS

Peter Elias[1]
Samuel Dekolo[2]
Olatunji Babatola[3]

ABSTRACT

The growth of world population has been of serious concern in the last few decades. Of particular worry is how earth's resources will match the concentration of human populations especially in developing countries. Associated with these are issues of urbanization, global warming and climate change which are also expected to have more impacts on poor peoples and places in developing countries. Responding to these issues has been problematic as we do not know expertly what will be the future scenarios especially in developing countries. It will be interesting to know the future trajectories of population growth, urbanization, urban land change (land use and land cover), and the socioeconomic conditions of developing countries. To this end various models have been evolved overtime for urban land use change forecasting but with more application in developed countries. How do we then make these urban change models more applicable to solving practical issues especially in developing countries? It is pertinent therefore to examine the current knowledge about these models; and to assess their usefulness, challenges and prospects in developing countries. It is against this backdrop that this paper by using extensive literature review examines urban land use change and modeling in developing countries. The historical developments of models was examined with the view to describing, classifying and characterizing the existing models, identifying the limitations to their adoption by decision makers, and suggesting ways to strengthen their relevance and applicability in developing countries. It concludes that models should be designed to clearly communicate their outputs to the practical users/policy decision makers. Besides, it suggests that since it may be difficult to calibrate models to have standard measurements or procedures, each region such as the developing countries should be treated in the context of its uniqueness with respect to urban dynamics, ecology and metabolism.

Key Words: Urbanization, Global environmental change, Land use change, Modeling, Developing countries

INTRODUCTION

Land has often been described as the foundation of all forms of human activities. It is from it we obtain food, shelter and space for every other activity. Being described as a resource it has economic value, however, it is finite in supply as its availability for human use is limited in the physical sense. Apart from atmospheric resources, man's natural resources (renewable or non-renewable) are land based; therefore, the use of land must be within sustainable limits (Beale, 1980).

Conceptually, land use is said to be characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (DiGregorio & Jansen, 1998). The use of land is referred to as various human activities that take place on

[1] Department of Geography, University of Lagos, Nigeria
[2] Department of Urban and Regional Planning, University of Lagos, Nigeria.

land e.g. residential, commercial, industrial, recreational, circulation, etc; which can be referred to as land's *social properties*. Land use is the output of man's reconstruction activities, which is according to determinate economic and social purpose. Thus, land-use is a process of turning *natural ecosystem* into *social ecosystem* (Brandon, 2000; Jianchen and Lin, 1999; Dekolo & Ogunleye, 2007). There are two basic factors that influence the use of land; these are natural and man-made factors. The natural factors (biophysical) include landform and topography, soil characteristics, availability of water and climatic conditions. On the other hand, man-made factors (social, economic and institutional) include socio-cultural values, land market, demographic characteristics, infrastructure, political and economic institutions, etc. Land use change may involve either conversion from one type of use to another or modification of a certain type of land use (Briassoulis, 2000). Modification of land use may involve intensification, densification, invasion and succession (income level or use) or change from non-urban use to urban, forest to farming or recreation and so on.

Land Use and Land-Cover are closely related and the investigation of changes in one will require a proper understanding of the other; while the former emphasizes social attributes of land and an expression of human activities, the latter emphasizes in particular its natural properties and it is defined as the biophysical cover of the earth's surface synthetically reflecting various elements in global surface covered with natural body or man-made features. Hence, land cover is the geographic feature which may form a reference base for applications ranging from forest monitoring, planning biodiversity, climate change, etc (DiGregorio & Jansen, 1998). Though land cover changes are basically driven by anthropogenic forces such as direct human use (agriculture, livestock, forest harvesting, urban and suburban development) and indirect incidental impacts (acid rain from fossil fuel combustion, crops damage resulting from tropospheric ozone created by automobile exhaust); some natural events like weather, flooding, fire, climate change and even ecosystem dynamics may also initiate land cover modifications.

Since land cover represents the resource base of our ecosystem, which is going through continuous change in time and space, with lack of appropriate data it has been difficult to assess the present and future impacts of the changes on the ecosystem (human and nature). Improved land cover and land use information is vital for planning and modeling future scenarios, which will ensure sustainable development.

Land use change is central to the sustainability debate; it is a major driving force of global environmental change and it affects the earth systems as seen in literature (Grimm, et al., 2008; Foley, 2005; Shao, Ni, Wei, & Xie, 2005; DiGregorio & Jansen, 1998). The challenge of environmental sustainability in urban areas has transcended the local problems to a global perspective having serious ecological repercussions.

Land use, though seen by many as a local environmental issue, has become a force of global importance. Worldwide, changes to forests, farmlands, waterways and air are being driven by the need to provide food, fiber, water, and shelter to the world's over seven billion population (Smith, 2011). The continuous expansion of urban land use in the last few decades has led to considerable losses of biodiversity and even farmlands, thereby posing a threat and potentially undermining the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, regulate climate and air quality (Beale, 1980; Welbank, 1994; Foley, 2005).

Pickett et al (2001) noted that cities are no longer compact and isodiametric aggregations but sprawling fractals or spider-like configurations. These changes have impact at various spatial scales: global, continental, regional and local. The consequences are reflected in urban climate change, the continuous depletion of the environmental resources and diminution of rural agricultural lands (Turner, 1997; Agarwal, Green, Grove, Evans, & Schweik, 2002).

There are several theories that have tried to explain land use change. Land use change theories, according to Briassoulis (2000), are sets of propositions used to understand the "what" of land use change and the "why" of this change. In other words, "a theory of land use change describes the structure of the changes in the uses of land from one type to another – and explains why these changes occur, what causes these changes, what are the mechanisms of the change" (Briassoulis, 2000). However, these changes, which could be environmental, economical and spatial transformations are complex and dynamic resulting from human-land interaction could be propelled by these four categories of driving forces: biophysical, institutional, technological and economic factors (Shao, Ni, Wei, & Xie, 2005).

Land use change analysis provides knowledge about "what", "where" and "why" changes have taken place in space and time. Moreover, models give better understanding of the land use change, the processes that shape it and its present and future impacts, thereby providing solid foundation for future policies and plans. The two principal objective of modeling are to *understand* and to *predict. Descriptive models* describe what currently exists and *predictive models* assimilate a set of data to simulate potential outcomes. Temporal models span the gap between the two by describing the transitional process that have been observed through time and forms a basis for future predictions (Aronoff, 2005).

Over the last decades, a range of models of land-use change have been developed to meet land management needs, and to better assess and project the future role of land-use and land-cover change in the functioning of the earth system. Land use change models may use a combination of methodology to make future predictions; many authors have characterized these models from various viewpoints (see Sui, 1998; Briassoulis, 2000; Veldkamp & Lambin, 2001; Agarwal et al, 2002).

The aim of this paper is to review developments in land use modeling, the challenges facing developing nations and the path to harnessing the advantages that come with land use modeling. This paper reviews the current state of the art in land use change modeling used in developing countries; it also examines the research gaps and prospects of land use change models applicability in the context of developing countries.

Overview of Current State of the Art in Land Use Change Model

Land use change models are tools for understanding and explaining the causes, locations, consequences and trajectories of land use dynamics. Models are a representation of "what is" (descriptive models) and "what will be" (predictive models); some models such as cellular automata are capable of capturing spatial complexities of urban and regional areas while also projecting into the future possible land use changes (Shao, Ni, Wei, & Xie, 2005). They represent part of the complexity of land use and urban systems and offer the possibility to test the long term consequences of decisions given selected variables. Moreover, when done in a spatially-explicit, integrated and multi-scale manner, land use change model facilitates projection, prediction and understanding of key processes in land use changes and probable impacts. The models offer the possibility to test the sensitivity of land use patterns to changes in selected variables. They also allow testing of the stability of linked social and ecological systems, through scenario building (Veldkamp & Lambin, 2001).

The development of most land use models have been driven by the need to project probable future impacts of land use change and the need for informed decision by planners and policy makers. While various modeling techniques and applications have emanated from developed countries, there are little significant contributions in developing countries due to limitations in technology and data availability and/or accessibility. Moreover, the complexities in urban systems and lifestyle in developing countries makes the direct transfer of models less feasible in spite of their sophistication (Tiglao, Tsutsumi, & Shimizu, 2003).

Over the past five decades, a range of models of land-use change have been developed to meet land management needs; in practical terms they play a role in assessment of past and future activities as well as prescribing optimum patterns of land use for a sustainable earth system. Various models identified in literature may be grouped according to the purpose of the model, the underlying theory, its spatial scale and temporal dimension, type of land use change under investigation and the solution technique used (Briassoulis, 2000).

Furthermore, Briassoulis (2000) developed a composite criterion for classification of land use change models known as *modelling traditions* (see table 1). However, Agarwal et al (2002) developed an analytical framework for reviewing these models based on three dimensions. Time and space are the first two dimensions, which provide a common setting for the operation of all biophysical and human processes; while the third dimension has to do with human decision making (Agarwal et al, 2002). In other words, the land use change processes takes place within the spatial and temporal context and are influenced by human decisions. Therefore, our ultimate goal is to have models that accommodates all three dimensions in terms of scale and complexity.

Having used expert opinion and extensive literature search, Agarwal and others (2002) discovered about nineteen different models (see Table 2) which fits into these three dimensions, they include among others Markov chain models, logistic function models, regression models, econometric models, dynamic systems models, spatial simulation models, linear planning models, non-linear mathematical planning models, mechanistic GIS models, and cellular automata models. However, these models were characterized from three methodological endpoints: *spatially explicit econometric models*, *spatial allocation (GIS) models* and *agent-based modeling*. While many models combine elements of two or all of these endpoints, the endpoints are useful because they represent the dominant approaches of different groups of modelers (Agarwal, Green, Grove, Evans, & Schweik, 2002).

The Spatially-Explicit and Econometric Model

Spatially-explicit econometric model were developed by economists to characterize the decisions of agents converting land between uses. These models make use of statistical approaches to determine drivers of economic processes which affects land use and make projections. The most common statistical technique used is multiple regression analysis, Markov chain analysis, principal component analysis, factor analysis, logistic regression other multivariate techniques (Briassoulis, 2000; Wainger, Rayburn, & Price, 2007).

The use of *statistical models* in land use change analysis dated back to the 1960's and has been used in several studies, especially analysis of its determinants. The most common probabilistic representation of land use change used in models is the Markov transitional matrix and transitional probabilities matrix. The *transitional matrix* 'T' represents the summary of land use change from land use group L_i to L_j within two observed points in time periods (time t_1 and t_2). The *transitional probability matrix* 'P' represents the probability of the change from one land use group to another is denoted by the following:

$$P = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1N} \\ P_{21} & P_{22} & \cdots & P_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ P_{N1} & P_{N2} & \cdots & P_{NN} \end{bmatrix}$$

The Markov chain model is one of the most used spatial statistical models describing dynamics of land use change and to predict future land use change. There are a lot of land use change studies in developed countries which have applied the Markov chain, however, only few in developing countries include applications in Nigeria, Chile, Kenya, China and India (See Fabiyi (2006); Fernando (2007); Mubea, Mundia, & Kuria (2010); Rimal (2011)).

Apart from the use of Markov chain models, principal components analysis and factor analysis are other examples of statistical models of land use change applied in developing countries. Odumosu (1992) applied a factor analysis method and principal component analysis to analyze the spatiotemporal changes and metropolitanization processes in Lagos. Eight key areas of the metropolitan character were identified and correlated with each other to determine processes responsible for changes; they include housing, transportation, residential and transportation mobility, rent, household structure, income, infrastructure, use of time and migration. He noted that socioeconomic conditions are keys to understanding urban growth and changes in developing countries.

Land use could be modeled in a discreet or continuous variable as highlighted by Briassoulis (2000). Area under consideration could be subdivided into identifiable zones, which could be *grid cells* or neighbourhood entities. However the size and shape of each zone depends on available data and spatial scales.

In *discrete statistical models*, land use types are distinguished and described as a function of a number of characteristics, which differentiate each cell from the other. The probability of choosing a particular land use type in a cell is a function of the utilities associated with the land use under consideration. An example of discreet model is the multinomial logit model highlighted in Briassoulis (2000).

For a continuous statistical model, the *dependent varaiable* could be the land use type and the *predictor variable* could be environmental and socio-economic values (e.g. population, employment, soil conditions, slope, climate, etc). These could be summed up in a generic equation and regression analysis is applied as follows:

$$LUT_i = a + \beta_1 X_1 + B_2 X_2 + \dots\dots\dots \beta_n X_n + \varepsilon$$

Where LUT is the area of land occupied by land use type i (in each zone or cell) and $X_{1,} X_2$ ...X_n are the independent or *predictor variable*, while 'E' is the error term (Briassoulis, 2000). An early application includes the "probabilistic model for residential growth" known as the North Carolina model by Chapin and Weiss (1968). Recently similar application has been used in the CLUE model (Briassoulis, 2000).

Econometric models of land use change make use of "economic models of individual decisions in which land owners choose a land use in a given period such that net expected profit over time is maximized" (Irwin, 2010). These models, entrenched in urban economic theories tend to model estimated changes in some determinants of land use (e.g. population, housing demand and employment) and convert these future estimates to land use requirements with the use of land use coefficient (Briassoulis, 2000). An example of econometric model is EMPERIC, a spatially explicit regional activity allocation model, which was developed for future forecasts of population, economic activity and land use pattern in metropolitan areas under various development scenarios. There have been few criticisms of the EMPERIC model that it is statistically biased and lacks insight into forces causing changes in the metropolitan structure, however, it is one of the few models that had several applications in the 1960 and 1970s - the Golden Age of Quantitative Analysis (Briassoulis, 2000).

Spatial Allocation and Gis-Based Models

Spatial allocation models were evolved in an attempt to simulate the distribution of units of growth among competing land uses in urban areas. Neighborhood conditions that suit certain types of land use change are simulated and allocated to specific locations (e.g., grid cells) to generate future land use (Wainger, Rayburn, & Price, 2007).

The spatial allocation model has been broadly attributed to the work of Ian Lowry, who initiated the *Model of Metropolis* in 1964. Lowry, considering the City of Pittsburgh, created a *Gravity type Model* based on the assumption that, all things being equal, the place of employment determines the place of residence. This is close to the concept of gravitation and spatial interaction, in which, human activities follows the law of gravity and land use types are determined by the laws of attraction and repulsion.

Even though urban models have been used consistently since the 1960s, GIS-Based land use models evolved in the 1980s. The integration has enhanced better visualization of models and sophisticated simulations of urban land use processes. Several authors have written about GIS-based modelling, however, the work of Sui (1998) gave a very good description of the four strategies for GIS-based urban models. These include: *embedding GIS-like functionalities into urban modelling packages; embedding urban modeling into GIS by software vendors; Loose coupling and Tight coupling (see Table 2).*

- **Modeling packages embedded with GIS-like functionalities.** This can be seen in a wide variety of modeling software with integrated GIS capabilities. GIS functions in the models provide platforms for data management, spatial analysis and visualization.
- **GIS software embedded with modeling capabilities.** Some GIS software has the capability to model land use change. Commercial GIS packages like ArcGIS have spatial modeling extensions using fuzzy logic and logistic regression, Idrisi has Cellular Automata functions, TransCAD etc. have sophisticated modeling capabilities. Since the demand for land use models is very low, there could be the problem of redundancy due to lack of use of such functions (Cheng, Masser, & Ottens, 2003; Sui, 1998).
- **Loose coupling.** This approach involves integrating GIS packages with modeling or a statistical package such as SPSS via data exchange formats or binary data format. Though redundancies may be overcome, there could be serious challenge in data conversion, errors and interoperability.
- **Tight coupling.** This embeds models with commercial GIS software packages through customized user defined applications, programs and scripts written by the end user. This will require some high level of expertise.

Agent-Based Models

Agent-based Modeling is now a dominant paradigm in land use simulation due to the increasing understanding that the complex systems of our cities emerges from bottom-up and are composed of highly decentralized and heterogeneous objects referred to as agents (Crooks, Castle, & Batty, 2007). Agent-based modeling consists of a "number of agents which interacts both with each other and with their environment, and can make decisions and change their actions as a result of this interaction" (Matthew et al, 2007 citing Ferber, 1999). Human decisions are principal factors of land use change. Those who make decisions at various spatial scales of land use: parcel, block, neighbourhood, district, town or regions are known as *agents* and the location of these decisions within defined locations may be referred to as *cells.*

Agent-based modeling has the capabilities of exploring micro-level behavior which have macro-level outcomes or repercussions. Theories of self-organization by various agents, spatial entities or actors reveal the interactive properties of the human and natural systems (See Cheng, Masser, & Ottens, 2003). Modeling land use and land cover dynamics in the context of developing countries will rely on micro scale data since the drivers of change in these countries are individual agents with distinct characteristics. Moreover, the emergence of mega-slums and sprawling nature of such regions cannot be divorced from socio-economic factors and their inherent lifestyles imposed on agents and actors.

Agent-based models adopt grid cells to model agents and fixed location in what is known as *cellular automata models*. Cellular automata models of land use change have been developed as processes or rules that determine land use change based on a great deal of spatially-explicit information. The model, which is attributed to the works of Alan Turing and John von Neumann in the 1950s, became popular in the 1970s when John Conway implemented it as a computer *Game of Life* (Batty M. , 1997).

Cellular Automata is a cell-based approach to model processes in two-dimensional space using a set of rules to determine the transformation of a cell from one state to the other. A typical CA will have these four components: cells, neighbourhood, state and rules. The cell is the smallest unit of a system while the neighbours are adjoining cells. The state may be type of land use, which may change over time based on some transition rules. The transition rule is that the state of a cell changes if something does or does not happen in its neighbourhood (Batty, 1997; Sudhira, 2004).

CA models have some advantages which include the simplicity of its construction and its ability to handle spatio-temporal dynamics. It can be integrated with Markov models and easily fitted into Raster GIS and can be manipulated to get series of result (IDRISI for example have CA capabilities).

Land Use Change Modeling in Developing Nations: The Challenges

In contrast to developed economies where land use change models have reached a matured state due to availability of computer technologies, scientific knowledge and good funding, the state of application in developing countries such as Nigeria have been left with disappointments. Challenges include data availability and accessibility, complexities of urban systems to model, applicability of available models imported from the west, lack of interest by policy makers and lack of indigenous models.

Tiglao and others (2003) proposed a framework for urban modelling in developing countries by first examining the issues at stake. They noted that only little work has been done in modeling cities in developing countries. Though models have been applied narrowly on planning problems, sensitive issues on equity and environmental sustainability have been neglected (Tiglao, Tsutsumi, & Shimizu, 2003). The issue of land use change is central to the sustainability debate; however, most studies carried out have focused on the analysis of change with very few projection of future land use scenarios to planners and policies makers. Apart from studies done at metropolitan levels, there are very few known to the authors on modeling land use change addressing sustainability at a regional spatial scale of a megacity in Sub-Saharan Africa (i.e. Lagos Megacity). The study was funded and carried out by the European Commission DG Joint Research Centre (See Berredo & Demicheli, 2003).

The study of Lagos Megacity done under the European Union's MOLAND project reveals an additional gap in modeling applications in developing country. The research was based on Cellular Automata in which projections of future land use changes were made for a 20 year period, however, the work was based on secondary data only (basically remote sensed images) and there was no primary survey on the actors and agents responsible for the changes.

It should be noted that there are few similarities and more differences in the urbanization process of developing countries and the western world. Therefore making isomorphic transfer of urban models from developed countries to developing ones is a mistake which underscores complex socio-economic conditions. For example, the social and economic inequalities disaggregated household structures and the ever growing informal sector and settlements (see Tiglao, Tsutsumi, & Shimizu, 2003) in developing countries could pose real challenge for modelling. Other issues of relevance here include the disconnect between data availability and accessibility and methods of communicating scientific data. Next to this are the ineffective methods of integrating interdisciplinary studies. The ability to present scientific findings across fields of knowledge is the fad. This calls for broad based models developed by broad minded rather narrow minded experts.

An overview of the cost of purchasing modeling packages as shown in Table 2 is quite high and some are not even available for purchase "off-the-shelf". This poses another major challenge for their use in developing countries. Moreover, those models that are free require more data input which are not easily available and/or accessible in some developing countries.

The Prospects of Land Use Change Models in Developing Countries

Land use change is a major issue in the understanding of man's social, economic and physical environment. Therefore a proper understanding of its process and drivers are indispensible. The possibility of understanding the present and future outcomes of land use decisions taken and their impacts have been made easy through land use change models. However, there are gaps in developing countries, which this paper has attempted to address. In spite of the gaps identified above land use change models have high prospects in developing countries if the following suggestions are considered:

- Models of the physical systems must not be divorced from the dominant socio-economic models and such models should be operated at different spatial-temporal scales.
- Future models should not only address land use change, but impact on energy, infrastructure and climate which have indirect effects of land use change.
- Batty (2010) also suggested the need for coupling models of infrastructure, energy into land use models. However, they must be made as simple, interactive, user friendly and with good visualization as possible (If possible web-based).

Besides, there is the need for the development of indigenous modeling platforms that will take care of both the physical systems and socioeconomic drivers of land use change. There is the need to review current curriculum and techniques of geospatial training programmes to train students in interdisciplinary ways to make them broad minded experts. This will require strong collaborations among institutions for exchange of knowledge and skills. Agencies involved in data gathering must recognize the need to evolve the appropriate scales for the collection of socioeconomic data. This must be adequately disaggregated into individuals, households, communities, local, national, regional and global levels. Moreover, government must also invest in cadastral mapping if the desire to assess, monitor, and predict land use changes are to be achieved. In addition, communities and socioeconomic sectors must be well organized to facilitate proper monitoring and forecasting.

CONCLUSION

This paper has attempted to review land use change modeling in the context of developing countries and has also highlighted the gaps and future expectations. It shows the immense contributions and applications of models in the developed countries which is not the case in the developing ones. Having reviewed closely modeling traditions, classifications and existing packages, there is a research gap to be filled, especially the need for modeling the processes as well as the drivers of change at a regional scale without leaving out the micro agents and processes seen in existing studies. This gives a new direction and agenda for research in land use change modeling by urban and regional planners in developing countries. It is high time modeling science be made to provide relevant answers to the myriads of problems facing developing countries today. This underscores the need for capacity building, redesigning/development of modeling science curriculum, investment in modeling platforms and acquisition of appropriate data sets to make the prospects of land use change modeling respond to needs of the day in developing countries.

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Table-1. Classification of Models of Land Use Change (Briassoulis, 2000)

Category of Modeling Traditions	Representative Models
Statistical and Econometric Models	• Linear Regression Models • Econometric Models (EMPIRIC) • Multinomial Logit Models • Canonical Correlation Analysis model
Spatial Interaction Models	• Potentials Models • Intervening Opportunities Models • Gravity/Spatial Interaction Models
Optimizations	• Linear Programming Models • Dynamic Programming • Goal Programming, Hierarchical Programming, Linear and Quadratic problem, Nonlinear programming models • Utility-maximization Models • Multi-Objective/multi-Criteria Decision Making Models
Integrated Models	• Econometric-Type Integrated Models • Gravity-Spatial Interaction-Based and Lowry-type Integrated Models. (E.g. Lowry Model). • Simulation Integrated Models (E.g. CUFM, TRANUS, CLUE-CR, Cellular Automata • Input-Output-based Integrated Models
Other Modeling Approaches	• Natural-Science Oriented Modelling Approaches (Ecological Modeling Approaches) • Makov Modeling of Land Use Change • GIS-Based Modeling of land use change

Table-2. A Review of Current Land Use Change Model

Model Nam /Date Developed	Developer	Overview	Cost	Expertise Level Needed	Strength	Weakness
California Urban Futures (CUF) Model: CUF 1 & 2 1995 & 1998	John Landis, Institute of Urban and Regional Planning, University of California at Berkeley http://www- dcrp.ced.berkeley.edu	-Simulating urban growth and policy impacts. -Uses Econometric models -GIS databases and mapping functions	Contact Developer	Medium	-Easy to use -Expandable -Integrate policies	-Availability -Limited to residential Land Use
California Urban and Biodiversity Analysis (CURBA)	John Landis, Institute of Urban and Regional Planning, University of California at Berkeley http://www- dcrp.ced.berkeley.edu	-Evaluates effects of urban growth patterns and policies on biodiversity and natural	Contact Developer	None	-Easy to use -Increases understand-ing on trends and patterns -Effect of	-Errors possible from limitations in expanding historical

1988		habitat quality - GIS databases and mapping functions			policies on growth are projected	growth pattern -Assume all urban growth the same -Human decision making not explicitly considered
DELTA 1998	David Simmonds Consultancy http://www.davidsimmonds.com/land-use.html	-Projects changes in urban areas, including the location of households, population, employment, and the amount of real estate development -GIS databases and mapping functions	Contact Developer	Extensive	-Forecast changes over short periods -User specified input and output -can be integrated with other packages	- Availability -Subject to strict licensing
Growth Simulation Model (GSM) 1997	Joe Tassone Maryland Department of Planning, Baltimore, Maryland. http://www.mdp.state.md.us	Projects population growth and new development effects on land use/land cover under alternative land management	Contact Developer	Medium	-Simulates land use changes as a function of population, employ-ment, etc. -easily customized -can extrapolate land use change area larger than study area	-need skilled program-ing for customizat-ion -lower mapping function
INDEX	Criterion Planners/Engineers, Inc. http://www.crit.com	Measures the characteristic s and performance of land-use plans and urban designs with "indicators" derived from community goals and policies	$15,000-$75,000	Extensive	-Customized to meet user needs -GIS mapping capability -monitors long / short range develop-ment	-Require detailed GIS expertise -land use plan being evaluated must be exogenous
IRPUD Model 1983 & 1998	Michael Wegener, Institute of Spatial Planning, University of Dortmund, Germany http://irpud.raumplanung.uni-dortmund.de/irpud/index_e.htm	Projects the impacts of long-range economic and technological change on housing,	Contact Developer	Extensive	-No submodel -Coarse spatial resolution	-studies impact of global/loca l policies High temporal resolution

		transportation, public policies, land uses, and infrastructure -uses data GIS format and SPSS				-Dynamic model for transport/land use interaction
Land Transformation Model (LTM) 1995	Dr. Bryan C. Pijanowski Michigan State University http://www.ltm.msu.edu	Integrates a variety of land use change driving variables to project impact on land use on a watershed level -Uses GIS data and neural network packages	Free	Extensive	-Easily understood GIS outputs -User defined GIS inputs -show drivers of historical changes	-limit in cell size -Extensive programming to couple GIS and neural network software - large memory need for processing -need training and experience
Land-Use Change Analysis System (LUCAS) 1994	Michael W. Berry, et al., Department of Computer Sciences, University of Tennessee http://www.cs.utk.edu/~lucas	Examines the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability. -Uses Open Source GIS (GRASS)	Free	Extensive	-Uses low cost open source GIS software -Flexible and interactive computing environment to those with expertise	-Rigid pixel based method -Fragmentation possible -Require expertise in programming and modelling -GRASS GIS package used not common
Markov Model of Residential Vacancy Transfer	Philip Emmi and Lena Magnusson Geography Department University of Utah www.geog.utah.edu/faculty/emmi.html	Explores changes in demand for various types of residential housing within a community	Free	None	-Simulates impacts of new vacancies and new entrants in residential locations -High accuracy	-no explicit simulation of land use changes -examines only discreet sectors of housing market
MEPLAN	Marcial Echenique & Partners Limited. Contact: Ian Williams www.meap.co.uk	Helps communities analyze the inter-related effects of land use and transportation and is designed to	$25,000	Medium	-Models interrelated variable in cities -Analyses different type of policies -Highly	-data intensive Calibration may be difficult -Validation of base year result may be difficult

		compare proposed plans/policies			synthetic and less reliance on large data	
METROSIM	Alex Anas & Associates http://www.acsu.buffalo.edu/~alexanas http://www.bts.gov/tmip/papers/landuse/compendium/dvrpc_ch1.htm#1.4.3	Uses an economic approach forecasting interdependent effects of transportation and land use systems and of land use and transport policies -Uses GIS formats and SPSS	$20,000-$30,000	None	-Rooted in economics and recognizes the role of market forces in changing land use -Rapid computer process Deals with land use policies and changes	-No GIS interface
The SLEUTH Model (formally Clarke Cellular Automata)	Keith C. Clarke, Department of Geography, University of California at Santa Barbara http://www.geog.ucsb.edu/projects/gig	Projects urban growth and examines how new urban areas consume surrounding land and impact the natural environment -Clarke Cellular Automata Urban Growth Model -Six types of data input required: Slope, Land Use, Exclusion, Urban, Transport, Hill shading	Free	Medium	-Concurrently simulates four types of growth (spontaneous, diffusive, organic and road influenced) -Graphical and statistical output -Alternative scenario projection	-does not deal explicitly with population, policies and economic impact on land use change
Smart Growth INDEX 1998	Criterion Planners/Engineers, Inc. (with Fehr & Peers Associates, Inc.) www.crit.com	Evaluates transportation and land-use alternatives and assesses their impact on travel demand, land consumption, housing and employment density, and pollution	Free	Medium	-Evaluate growth scenarios and plan designs -High GIS functional-ity	-Require detail GIS data and expertise -Coded method of allocating growth cannot be modified by users.

		emissions -GIS-based				
TRANUS 1997	Modelistica http://www.modelistica.com/tranus/	Analyzes the effects of land-use and transportation policies or combinations of policies on the location of various activities and the land market -SPSS and GIS required	$5,000-$10,000	Medium	-Integrated land use transport model commercially available -User friendly -GIS interface -Wide applications at various scales -Annual upgrades	-Not fully a traffic model -Need GIS package to map output
UGrow	Wilson W. Orr Prescott College http://www.prescott.edu	Projects long-term changes to communities in response to changes in transportation and fiscal policies	Free	None	-A whole systems approach -Highly adaptable -understanding is built	-Need continuous support from consulting team -Not a projecting tool
UPLAN	Robert Johnston, Dept. of Environmental Science and Policy, University of California at Davis http:// ice.ucdavis.edu	Creates alternative development patterns in response to changes in development and fiscal scenarios -Need GIS to creat maps	Free	Medium	-Easy to use -Customiza-ble -Integrated with GIS -Grid cell can be as low as 25mX 25m	-Lacks sophisticated modeling
UrbanSim 2000	Paul Waddell, Daniel J. Evans School of Public Affairs, University of Washington http://www.urbansim.org/	Explores how the interactions between land use, transportation, and public policy shape a community's development trends and affect the natural environment	Free	Medium	-Reflect real world process Dynamic behavior that make it transparent to policy maker -Open source and free source codes -High visualization capability	-High data requirements -limited experience to current applications -Still evolving
What if? 1997	Dr. Richard E. Klosterman (as Community Analysis and Planning Systems, Inc) http://www.What-if.com	Supports comprehensive community land-use planning in regard to determining land	$2,500 and $250 for academic license	Medium	-Easy to use -Customizable -Integrate easily with GIS packages	-Lack sophisticated modeling -Cannot measure spatial interaction -limited in

		suitability for development, projecting future land-use demand, and providing the capability to allocate the demand to the most suitable location			-Has inbuilt GIS and accept ESRI shape files -Flexible Data requirement	discreet choice theory -does not explicitly model behaviour of actors
CLUE (Conversion of Land Use and it Effect) 1996	Tom Veldkamp, Louise Fresco and Peter Verburg http://www.ivm.vu.nl/CLUE	The CLUE model is a dynamic, spatially explicit, land use and land cover change model predicting changes at regional and local scales. Simulates top-down and bottom-up effects	Free	Medium	-Multiscale applications	-Limited considerati on of economic/ institutiona l factors

Sources: (Agarwal, Green, Grove, Evans, & Schweik, 2002; U.S. EPA, 2000)

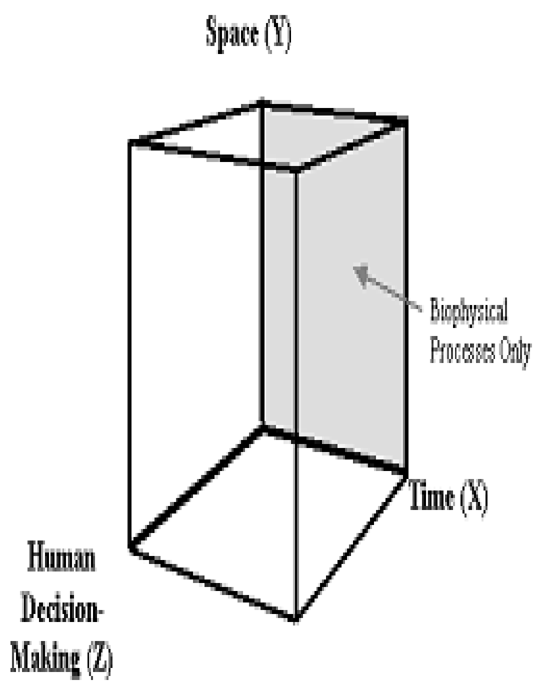

Figure 1. Three-Dimensional Framework for Reviewing Land Use Change Models (Agarwal et al, 2002).

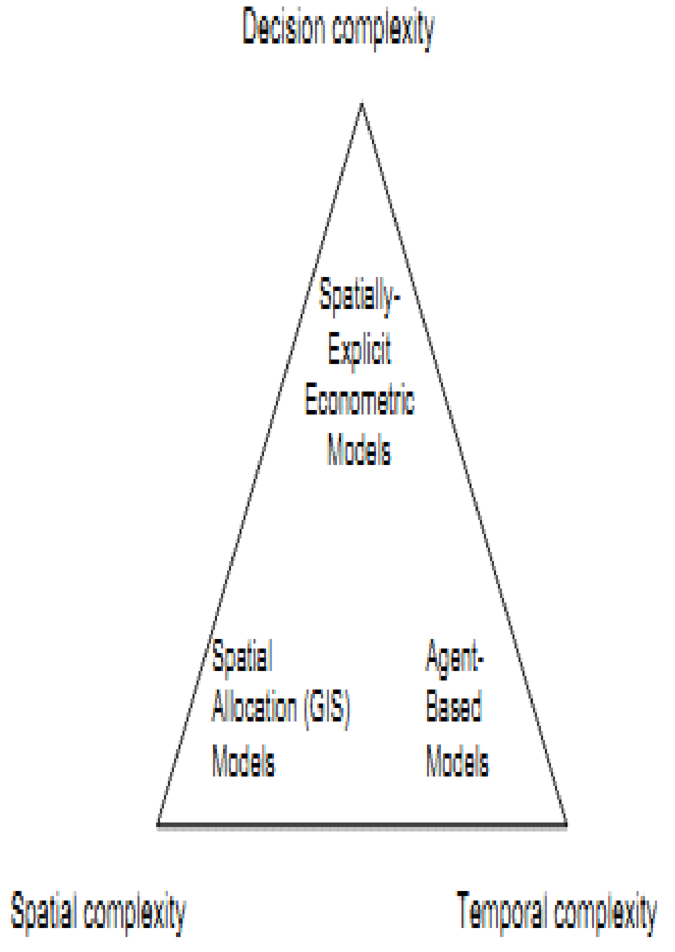

Figure 2. Model Classification Framework Based on Structure (Adapted from Agarwal et al (2002); Wainger et al (2007)

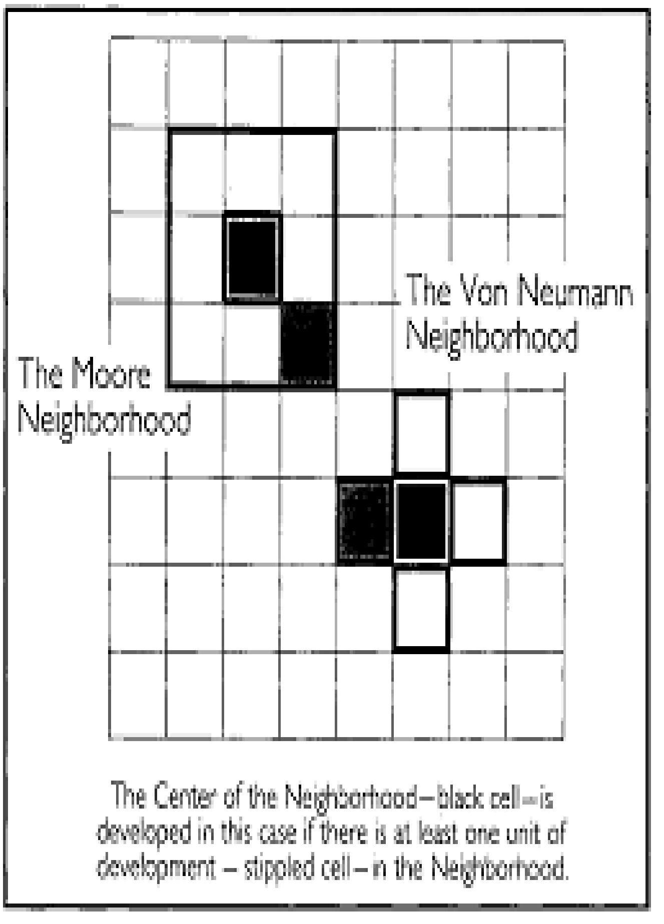

Figure 3. Cellular neighbourhoods (Source: Batty, 1997)

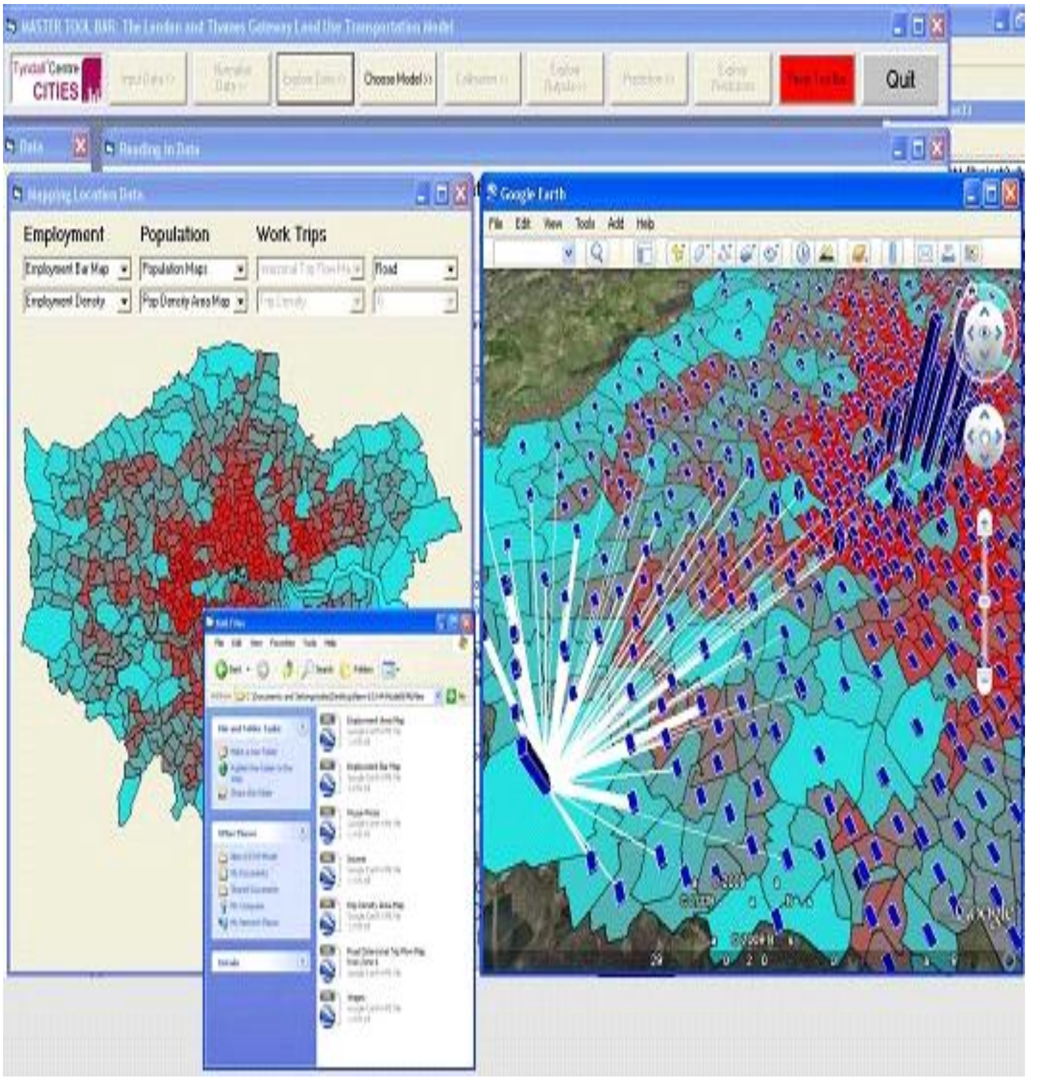

Figure 4. A web-based interactive Land Use Model Platform (Source: Batty 2010)