United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-00/098
September 2000
www.epa.gov

EPA

Projecting Land-Use Change

A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns

EPA/600/R-00/098
September 2000
www.epa.gov

Projecting Land-Use Change:

A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns

Science Applications International Corporation
11251 Roger Bacon Drive
Reston, VA 20190-5201

Contract #68-C7-0011

Project Officer
Susan Schock
U.S. Environmental Protection Agency
Cincinnati, OH 45268

National Exposure Research Laboratory
National Health and Environmental Effects Research Laboratory
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

Notice

The summaries of land-use change models contained within this report do not reflect the actual use of these products. Information presented on the function and capabilities of each model was collected largely through independent research of published materials such as users' manuals and Internet sites. The model developers have reviewed and verified the information compiled for their specific products, ensuring the accuracy of the material presented in this report. Significant efforts were made to explore and incorporate all land-use models currently available for public use during the project period. However, the population of such models is continually changing and it is recognized that any compilation will ultimately exclude one or more relevant models.

Preparation of this document has been funded wholly or in part by the U.S. Environmental Protection Agency. It has been subjected to the Agency's review process, and has been approved for publication as NHEERL draft number OD-01-001. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This report should be cited as follows:

U.S. EPA, 2000. Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns. EPA/600/R-00/098. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH. 260 pp.

Acknowledgments

This report reflects an uncommon degree of collaboration among the three laboratories of the U.S. Environmental Protection Agency's Office of Research and Development (ORD), as well as selected program and regional offices across the Agency. Funding was provided by the Administrator's Office of Congressional and Intergovernmental Relations (OCIR) and ORD's National Exposure Research Laboratory (NERL), National Health and Environmental Effects Research Laboratory (NHEERL), and National Risk Management Research Laboratory (NRMRL). Laura Jackson of NHEERL directed the development of this report, with support from Jim Kreissl of NRMRL. Many thanks go to Linda Rimer for lead sponsorship through OCIR's Sustainable Urban Environments Task Force.

Science Applications International Corporation (SAIC), under contract to ORD, provided key technical support. Led by Cary Gaunt, SAIC's staff included Kellie DuBay, Christine Garrow, Jana Lynott, Mary O'Kicki, Michael Palace, Daniel Sklarew, and Elizabeth Smeda.

In addition, the following people made essential contributions to this report:

<u>Technical Workgroup</u>

(Laura Jackson, U.S. EPA National Health & Environmental Effects Research Laboratory)
(Jim Kreissl, U.S. EPA National Risk Management Research Laboratory)
Ron Matheny, U.S. EPA National Exposure Research Laboratory
Peter Washburn, U.S. EPA Office of Congressional and Intergovernmental Relations *(formerly)*
Mark Flory, U.S. EPA Office of Congressional and Intergovernmental Relations
Geoff Anderson, U.S. EPA Office of Policy and Reinvention
John Thomas, U.S. EPA Office of Policy *(formerly)*
Victor McMahan, U.S. EPA Office of Air
Vicki Sandiford, U.S. EPA Office of Air
Mark Wolcott, U.S. EPA Office of Air
Sumner Crosby, U.S. EPA Region III *(formerly)*
Tom Brody, U.S. EPA Region V
Steve Goranson, U.S. EPA Region V
Michael Culp, U.S. Dept. of Transportation, Federal Highway Administration
Tom Gunther, U.S. Dept. of Interior, Office of Water and Science
Joe Tassone, Maryland Department of Planning
Bernie Engel, Purdue University
Dick Klosterman, University of Akron
Bob Johnston, University of California-Davis
Bryan Pijanowski, Michigan State University
Eliot Allen, Criterion Planners/Engineers, Inc.

Peer Reviewers
Chris Bird, Alachua County, Florida
Angela Harper, County of Henrico, Virginia
Robert Holm, City of Indianapolis, Indiana
John Schlegel, Clark County, Nevada
Ellen Walkowiak, City of De Moines, Iowa
Morgan Grove, USDA Forest Service
Tracie Jackson, U.S. EPA Office of Air

Model Developers
Finally, grateful recognition goes to the model developers for their patience and helpfulness in providing two reviews and final approval of all model information. The name of each model developer is featured at the top of the respective model fact sheet in Section Five.

Abstract

Many potential clients for land-use change models, such as city and county planners, community groups, and environmental agencies, need better information on the features, strengths, and limitations of various model packages. Because of this growing need, the U.S. Environmental Protection Agency (EPA) has developed a selective summary of 22 leading land-use change models currently in use or under development. Partners in scoping this effort include the U.S. Departments of Transportation and Interior, the academic and consulting communities, and multiple program and regional offices across EPA.

EPA's Office of Research and Development (ORD) initiated the land-use change models summary in order to improve its ability to assess and mitigate future risk to ecological systems, human health, and quality of life. Target user groups for this publication are:

- Community planners, citizens, and decision makers who are seeking tools to analyze future land-use scenarios;

- EPA program office and regional staff who support communities with planning tools and information for sustainable development; and

- ORD modelers and research planners who are currently assessing land-use models and gaps in the state of the science.

Contents

Page

Exhibits

1.0 Using This Guide

1.1 What Does this Guide Cover?

This guide provides a summary of 22 computer modeling tools that can be used to assess the impacts of community actions and policies on land use, and the reciprocal effect of land-use changes on certain community characteristics. In essence, it provides the avenue through which one can begin the process of identifying the best land use modeling tool to help accomplish effective Smart Growth planning. While a host of traditional planning tools (such as zoning and easements) do play a large role in Smart Growth planning as *management* tools, these types of tools are not discussed in this guide. Rather, the guide focuses solely on one important *decision-making* tool–land-use change models.

The models summarized in this publication are considered today's leading land-use change models currently in use or under development. By using this guide, the reader will be able to readily determine the models' applicability, data and resource requirements, strengths and limitations, and costs. Of note is the fact that each model summarized in this guide has its own unique attributes and differs in ease of use. The models range from the simple (i.e., they can be used by a nontechnical user on a desktop computer) to the complex (i.e., they require consulting expertise, detailed data, and sophisticated computer technologies). Some consider land use in the context of employment and housing activity, while others explore the suitability of land for various intensities of use. Some models provide statistical output in the form of tables, while others provide more visual output, such as maps. Because such a diverse array of land-use change models exists, it is often difficult to identify the most useful one for a given situation, let alone easily understand its individual applicability, strengths, and limitations. This guide attempts to make a potentially difficult task much easier by providing background information on why there is a need for planning models, a brief overview of the types of planning models, steps on how to choose the right model for your needs, and the essential general and technical information on 22 leading land-use change models.

Please note that this guide does not cover all models pertaining to growth-related issues, such as transportation or environmental quality models. The discipline of modeling transportation/land-use interactions is well established and several compendia already exist that document and compare leading models of this type (e.g., Southworth, 1995; Miller et al., 1999; Parsons, Brinckerhoff, Quade, and Douglas, Inc., 1999). As for environmental quality models, a companion document to this one is currently under development to characterize models projecting the environmental impacts that may result from land-use change. Many of the models contained within this summary, however, incorporate sufficient flexibility to evaluate, with appropriate data, these and other growth-related issues.

1.2 Who Should Use this Guide?

Anyone who is interested in analyzing land-use changes will find this guide beneficial–from federal agencies that support state and local sustainable development efforts, to state and local organizations that develop and implement comprehensive plans and growth-management policies, to students and other interested citizens investigating land-use change. If you find you are grappling with questions surrounding physical growth and change in your community, but do not know the best way to find the answers, this guide is for you. Although many types of individuals and groups can use this guide, EPA's primary intention is to meet the informational needs of the following audiences:

- **Land-Use Planners and Decision Makers**. On the local level, land-use planners play a key role in guiding the process of community growth and development. They help a community achieve its vision for the future by overseeing the development permitting process, ensuring that local zoning ordinances are followed, and modifying plans to reflect the changing goals of the community. They require sound information on how different land-use decisions will impact the community's quality of life. Land-use planners not only use that information to perform their jobs, they share it with other members of the community to aid in other decision-making processes. Understanding which models are available and the type of information they can provide will help land-use planners and decision-makers select the most appropriate tools to assist in community land-use decisions.

- **Citizens**. Defining and fulfilling the vision of a community requires the participation of community citizens. Land-use change models can assist community members in determining the vision for their community by providing them with the information necessary to support–or reject–policies affecting land use. Community members, both individuals and organizations, who are focused on improving the quality of life for the overall community will benefit from an increased awareness of these decision-making tools.

- **Researchers**. Researchers include federal representatives and academic staff who support communities with new planning tools and information. Members of this group often participate in the development and assessment of land-use tools. In addition to assessing existing tools, researchers identify gaps to determine which other types of information or capabilities communities may need to make sound decisions about growth and development. The summary of land-use change models contained in this guide will provide researchers with a better understanding of the tools currently available to communities and the direction their research should take in the future. Supplementary technical information that may be particularly helpful to researchers can be found in Appendix B.

1.3 How Should I Use this Guide?

In addition to providing summary information on 22 land-use change models, this guide provides background information on the need for these models and the key considerations for selecting the appropriate model for your community. This guide is divided into five sections, plus appendices. Because this guide was written for a large and varied audience, not all sections and appendices will be relevant to all users. The table below provides a descriptive outline of the guide and indicates the target audience for each section/appendix based on the user's knowledge level of land use policy, planning, and modeling. If you are relatively new to land use policy and planning and don't know much, if anything, about modeling, you would fall in the *limited* knowledge category. Some sections provide background information that may be useful for you. However, if you have moderate to substantial land use policy and planning experience and know the technical aspects of modeling, your knowledge level would be considered *extensive*. A reader with extensive knowledge may wish to avoid the sections covering background information but not want to miss the more technical information provided in Appendix B. Use Exhibit 1-1 to determine how to navigate this guide as appropriate for your needs.

Exhibit 1-1. Descriptive Outline of Guide Sections and Appendices

Knowledge Level		**Section/Appendix**
Limited	**Extensive**	
✔	✔	**Section 1.0: Using This Guide**
✔		**Section 2.0: Background** This section highlights the questions facing growing communities and the need for land-use models as a tool for better planning decisions and smarter growth.
✔		**Section 3.0: Decision-Making Tools for a New Planning Approach** This section provides a general overview of models–what they are, how they work, and what type of information they can provide. It describes the evolution of land-use change models, discusses how geographic information system (GIS) technology serves as a key component of this emerging modeling approach, and briefly describes the potential for integrated planning and decision-making systems.
✔	✔	**Section 4.0: Selecting the Best Land-Use Model**

Knowledge Level		Section/Appendix
Limited	**Extensive**	
		Selecting the best model for your community involves having a clear understanding of the project(s) being studied, the questions needing to be addressed, and the capabilities the community has to answer these questions. This section presents an overall process for selecting a land-use change model. It also presents specific criteria for selecting the right model from a host of choices.
✔	✔	**Section 5.0: A Summary of Current Land Use Models** This section explains how 22 land-use change models are summarized in this guide and how the summary was developed. It includes a sorting of the models based on 5 key selection criteria and a general fact sheet for each model. The fact sheets provide contact information, a brief introduction, reference information, the data and resources needed to run the model, the type of information produced by the model, a description of the model's strengths and weaknesses, how to obtain preview copies of the model, and case study information.
✔	✔	**Appendix A. Comparative Matrices on Land-Use Models** These matrices include, for each model, selected information presented in the general fact sheets in Section 5.0 and in the technical fact sheets in Appendix B, as well as some additional information, in a format that allows for quick comparisons between models.
	✔	**Appendix B. Technical Fact Sheets on Land-Use Models** These fact sheets complement the general fact sheets in Section 5.0. They include, for each model, information on the spatial and temporal resolution and scale of the model, input pre-processing requirements, model assumptions, setting parameters, comparing scenarios, output post-processing requirements, and next steps for model development.
✔		**Appendix C. Current Trends in Community Growth and Planning** This appendix: 1) describes the traditional approaches used in community planning that have, in conjunction with other factors, led to growth and development patterns with detrimental impacts on a community's overall quality of life, 2) explains the wide array of these impacts, and 3) provides an overview of the initiatives set in motion nationwide to put community planning on the path toward "smarter," less detrimental growth and development.
✔		**Appendix D. Key Terms and Definitions**

Knowledge Level		Section/Appendix
Limited	**Extensive**	
✔	✔	**Appendix E. References**

2.0 Background

Community citizens, planners, and decision makers often struggle to balance the demands of growth with the desire to preserve the natural environment, unique community characteristics, and other cherished quality-of-life attributes. To accomplish this balancing act, it is important to ask the right questions about the benefits and consequences of growth. It is also necessary to have the right tools to integrate and evaluate a diversity of information as a means of obtaining reliable answers.

This guide focuses on one type of tool–computer models that help explore the combined effects that social policies, individual behavior, and other drivers have on land-use change. Land-use change models are an essential component of a comprehensive approach for communities to project and evaluate the potential consequences of policy decisions and other actions on land-use patterns in their project areas. In addition, some of these models explore the reciprocal effects of changing land use on selected community characteristics such as commute distances, availability of open space, and environmental conditions. This guide can be used to help identify and distinguish individual characteristics of 22 leading land-use change models for selection of the best model for a particular community. The model information is presented through a series of general and technical fact sheets, as well as through matrices comparing key features across each model (see Section 5.3 and Appendices A and B).

2.1 Defining Community

The term *community*, as used throughout this guide, is EPA's definition, and relates to geographically based areas of varying sizes:

> *...a geographic area within which different groups and individuals share common interests related to their homes and businesses, their personal and professional lives, the surrounding natural landscape and environment, and the local or regional economy. A community can be one or more local governments, a neighborhood within a small or large city, a large metropolitan area, a small or large watershed, an airshed, tribal lands, ecosystems of various scales, or some other specific geographic area with which people identify.*
> –EPA, Sustainable Development Challenge Grant, *Federal Register*, Vol. 64, No. 126, July 1, 1999

Defining *community* in this way draws attention to the fact that many people's interests are at stake when discussions involve transforming land or existing structures into other forms.

2.2 Growing Pains

Along with tremendous opportunities for growth come welcomed benefits but also potentially complex problems. Our thriving economy has paved the way for new and more jobs, burgeoning tax revenues, added services, and various amenities, but these assets are often accompanied by rapid low-density development that can be hard to manage. This type of growth is commonly known as *sprawl*. Low-density development that leapfrogs outward from city centers, single-use zoning that separates one type of land use from another, and a heavy reliance on cars for transportation, are all characteristics of sprawl. Farmland and natural habitat are being converted to highways, housing developments, and strip malls. Older neighborhoods are being turned into new forms of multi- or single-family dwellings, often displacing older residents and leading to a deteriorating sense of community. People and businesses are moving away from the urban core, which can lead to central city and inner suburb decay and the accompanying isolation of disadvantaged populations left behind. As sprawl moves across the land, replacing significant amounts of open space, many communities are finding that they are consuming land at rates significantly higher than their populations are growing. In some cases, costs incurred by such growth are exceeding the benefits communities are receiving.

So how do communities accommodate this rapid development? How do we estimate all of its direct and indirect impacts? Furthermore, how will our decisions affect specific land-use patterns? Our communities? Land-use change models can assist in evaluating alternative futures and potential consequences of those alternatives. With these models, the user can begin to understand the complex array of actions and interactions associated with development by projecting the conversion and loss of land that occurs as a result of development and community policies.

2.3 Asking the Right Questions

The first step toward turning growing pains into community gains is to understand the complex dynamics that affect the results of development. A community *can* achieve growth while preserving valued characteristics, but stakeholders must first identify, ask, and answer questions that will allow them to make informed choices. Exhibit 2-1 illustrates a range of potentially helpful questions involving land-use change and its economic, fiscal, social and environmental impacts. When these questions are reviewed and a community develops ones of its own, it is likely that many will directly or indirectly involve land use.

In general, there are two *direct* ways a project may affect land use: 1) by consuming open space, or 2) by converting existing land uses to alternative ones. A project also may seed *indirect* actions that could affect how land uses change. For example, a new road may need to be built or an existing one widened; additional housing may be needed for new employees, or other businesses may need to be brought in to support the new development.

The many factors driving land-use change are diverse and often interrelated. Communities desiring to grow may offer a range of incentives to attract new development, such as tax breaks and subsidies. A new road or other transportation alternative may open up a new part of town. Or, utility services may expand to increase the development potential of a specific area. When factors such as these take place simultaneously, potentially complex situations develop. For example, a series of tax incentives and other subsidies may lure a new shopping mall to town. Developers and investors may then decide to build the mall on the outskirts of town because property is cheaper or other attractive incentives are being offered. The location of businesses away from the urban core results in a loss in the central city's tax base often leading to urban decay.

Furthermore, because the mall is built on the outskirts, agricultural land or other natural resources may be consumed. To accommodate the increased traffic flow and new traffic patterns, the transportation infrastructure would need to be enhanced. These transportation efforts, in turn, could consume more open space and/or provide pathways to additional lands that are more attractive to businesses and residential developers. As a result of these actions, local property taxes may need to increase in order to extend the existing infrastructure to these new developments. As property taxes increase, landowners that generate inadequate revenues (e.g., farmers) may be forced to sell their properties. On the flip side, communities may consciously or inadvertently offer disincentives for development through road tolls, utility fees, taxes, and planning restrictions. These disincentives could deter new businesses or favor one development over another.

As illustrated above, when one land use changes, it can trigger a change in another, creating a ripple effect. As a result, the community's public infrastructure may become overburdened. Traffic congestion may increase. Water, sewer, and other utilities may need bolstering. Pollution is likely to increase when open space is converted to impervious surface or more cars are added to area roads. Important natural habitats may be lost to strip malls, commercial

Exhibit 2-1. Questions Facing Growing Communities

Impacts on Costs of Services and Revenues
- How will this project affect the school system?
- Will other public services change as a result of this project?
- Will infrastructure costs (such as water, sewers, and roads) change due to this project?
- Will local tax revenue increase as a result of this project?
- Will the project "pay for itself"?

Impacts on Local and Regional Economies
- Will the project make the community more competitive in a commercial sense and more attractive to other business?
- What will be the project's impact on the cost of housing and property values in the community?
- Will the project have a negative effect on other communities in the area?

Transportation Impacts
- Will the project increase traffic congestion?
- Will the project provide ample and safe parking for residents/customers/employees?
- Will people who cannot drive be able to get to jobs, shopping, and services, such as doctors?

Environmental Impacts
- Will the project affect the amount of available green space, flood plains, and natural habitat?
- How will the project affect the consumption of energy and other natural resources?
- What will be the project's impact on water and air quality and quantity?

Social Impacts
- How will the project change the character of the community?
- How will the project affect disadvantaged populations?
- How will important community attributes (e.g., historic/cultural sites) be affected by the project?

Long-Term Considerations
- What other land-use changes will be encouraged by this project?
- How will impacts evolve over time?

Source: Adapted from *Why Smart Growth: A Primer,* ICMA and the Smart Growth Network, 1998 buildings, and housing. Newcomers may demand significant expansions of public services. Unfortunately, these new needs may end up exhausting more money than the new development can generate.

2.4 Using the Right Tools

Trying to determine how community growth and change affect land-use patterns can be very difficult. Fortunately, land-use change models are a tool that can make the process easier. However, caution should be taken when using model results. Models are estimation techniques–they are not an exact science and their results should be understood in the context of the qualifications, assumptions, and limitations of the model. Models rely on data and mathematical equations to simulate the "real world." They are only as good as the quality of data used and the decision rules and assumptions applied. Models are tools that can help develop policy when used carefully and in conjunction with other information.

Traditionally, computer models used in community planning have focused on regional economic trends or transportation-related impacts of economic growth. Such tried-and-true models have been around for a long time (see Exhibit 2-2). But now, with the advent of improved data collection methods and data accessibility, more affordable and advanced computer systems and technology (e.g., the growing popularity of geographic information systems), and an increasing emphasis on sustainable community development (i.e., Smart Growth), models that address the land-use consequences and environmental impacts of growing communities are becoming more popular. These more spatially explicit models seek to understand the dynamics of land-use change in a community setting. This innovative approach is a relatively new and rapidly changing field. At present, there is a lack of easy-to-use, well-organized information that can assist communities–the predominant users of land-use change models–in selecting the most appropriate tool. Hence, the need for this guide.

Exhibit 2-2. Selected Summary Reports on Transportation Models

Hunt, John Douglas, David S. Kriger, and Eric J. Miller. 1998. *Current Operational Urban Land-Use Transport Modeling Frameworks*. Submitted for presentation at the 78th Annual Meeting of the Transportation Research Board.

Parsons Brinckerhoff Quade & Douglas, Inc. 1999. *Land Use Impacts of Transportation: A Guidebook*. Report 423A. National Cooperative Highway Research Program. Washington, D.C., National Academy Press. Transportation Research Board.

Simmonds, David. 1995. *Available Methods for Land-Use/Transport Interaction Modeling*. A white paper by David Simmonds Consultancy.

Southworth, Frank. 1995. *A Technical Review of Urban Land Use-Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies*. U.S. Department of Energy, Oak Ridge National Laboratory: Publication number ORNL-6881.

Texas Transportation Institute. 1998. *Travel Model Improvement Program, Land Use Compendium*. DOT-T-99-03. U.S. Department of Transportation, U.S. Environmental Protection Agency.

Texas Transportation Institute. 1995. *Travel Model Improvement Program, Land Use Modeling Conference Proceedings. Final Report*. DOT-T-96-09. U.S. Department of Transportation, U.S. Environmental Protection Agency, and U.S. Department of Energy.

EPA's Office of Research and Development (ORD) is seeking to fill this gap. ORD spearheaded a comprehensive research team who examined and compared a variety of leading land-use change models currently being used or under development that could be employed by states and local governments and/or by EPA in conjunction with other models. The model inventory and summary information presented here is the result of this endeavor.

3.0 Decision-Making Tools for a New Planning Approach

Communities across the nation are choosing to complement traditional planning approaches with analytical decision-making tools to help them plan their sustainable futures. Today, with recent technological advances, a number of technologically-based tools are available to communities to use for assessing the impacts of various planning decisions and to help balance the demands of growth, environmental sustainability, and quality-of-life needs. Technologically-based tools such as models and geographic information systems (GISs) can provide increased clarity on probable or alternative outcomes, and thus enable decision-makers to more effectively use traditional planning tools. This section provides a brief overview of models and GISs, as well as integrated planning and decision-making systems which are part of the next evolution of modeling capabilities.

3.1 Models: An Overview

Models of many kinds have been used by a host of diverse professionals. Transportation engineers use models to project the number of commuters that will travel by car versus those who will make their trips by transit; economists use models to represent the flow of dollars within a regional economy; and biologists use models to describe the impact water pollutants will have on living organisms. In essence, a model is a simplified representation of a real-life system. By representing reality with only those variables that truly affect the behavior of the system, and by clarifying the relationships between those variables, the assumed "real world" is broken down into a form amenable to analysis (Taha, 1976).

Models can range from simple spreadsheets that provide order-of-magnitude estimates to highly complex simulations that require the use of a super-computer. Simple models provide rapid estimates with minimal effort and required data input. Technically-complex models provide the greatest level of accuracy, but they are usually much more costly in terms of data needs, hardware and software demands, and required professional expertise.

The four main types of planning models (land-use, transportation, economic, and environmental impact) are briefly described below. The models summarized in this document are considered land-use models but many have elements of the other three model types, as well as geographic information system (GIS) components.

Land-Use Models

Land-use models often incorporate a variety of land use categories as inputs and, thereby, can account for different subclassifications of urban and nonurban land use such as commercial, industrial, and agricultural, and even more detailed subclassifications such as density of residential use and type of commercial/industrial development (see the Anderson land classification system in Appendix C, Exhibit C-2). Some models offer an environmental approach and project, for example, the impact of transportation and land-use choices on air and water quality. Many of the more user-friendly models are integrated with GISs to become spatially explicit decision-support systems with relational database technology.

The common denominator of the models summarized in this guide is that each projects changes in land use. Understanding these models comprehensively, however, requires a basic understanding of the components of transportation and urban economic models–the foundations of many of the land-use models described in this report. Two major federal actions in the early 1990s added momentum to the integration of transportation and economic models and to the development of land-use models. In 1990, Congress passed the Clean Air Act amendments, which mandated that metropolitan areas look at the relationships between transportation and air quality. One year later, Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, TEA-21's precursor surface transportation law. ISTEA required transportation planners to consider the likely effect of transportation policy decisions on land use and development, and the consistency of transportation plans and programs with provisions of all applicable short- and long-term land-use development plans (Deakin, 1995).

Transportation Models

In the United States, both urban transportation and economic modeling began in earnest in the mid-1950s. Today, modern transportation models use some variant of the Urban Transportation Planning System (UTPS) models, which are characterized by a four-step, single-destination, separable-purpose, and daily trip-based approach. Using the following four steps, transportation models answer questions about future travel patterns:

- ***Trip Generation:*** How many trips will be made?
- ***Trip Distribution:*** Where will the trips be?
- ***Mode Split:*** Which modes (automobile, transit, cycle, or on foot) will be used?
- ***Traffic Assignment:*** What routes will be used and at what time of day will the trips be taken? (Beimborn et al., 1996)

Economic Models

Urban economic models project employment, population, wage rates, rents, incomes, and prices, among other variables, for different geographic areas. Until recently, these models tended to be used in for projecting economic growth rather than estimating the impacts of transportation policies on land use markets.

Environmental Impact Models

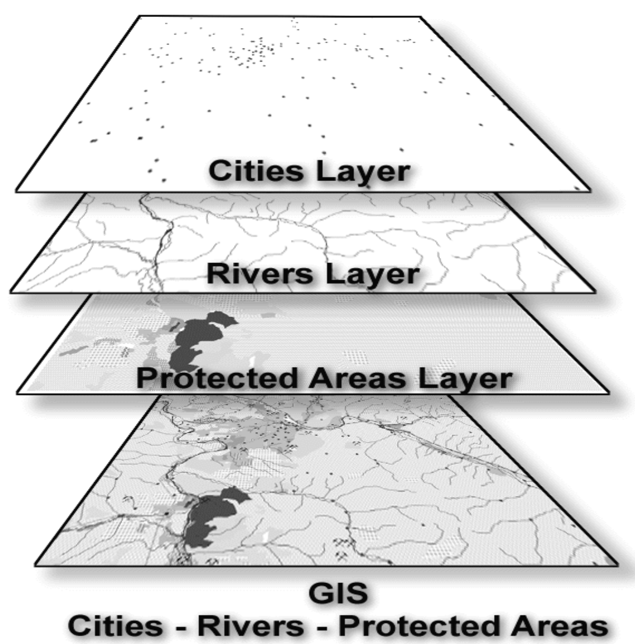
Many different types of models have been developed to assess the impacts that both natural and anthropogenic changes can have on the environment. These models range from projecting the long-range transport of pesticides to evaluating the impacts of vehicular emissions on air quality. More recently, models have been developed to address the effects that human induced land use changes can have on different aspects of the environment including surface water quality, groundwater recharge and pollution, habitat fragmentation, wildlife loss, floral and faunal community composition, and impaired ecosystem function. A great many of these models are watershed models, or models that examine the relationship between land uses in the watershed and water quality including nutrient loading, fecal coliform loadings and urban storm water runoff.

3.2 Geographic Information Systems (GISs)

Accompanying the proliferation of personal computers is the explosion in the acceptance and use of geographic information systems (GISs). GISs combine land-use mapping capabilities with relational databases and statistical analysis tools to enable planners to link numerous types of information, rapidly perform sophisticated analyses, and effectively communicate complex information with maps and graphical reports. They are powerful tools that could be a component of a model or modeling system. GISs are used to explain events, visualize trends, project outcomes, and strategize long-term planning goals. For example, using a GIS, a planner can map population density along a transportation corridor and evaluate whether there will be sufficient ridership to support public transit. Information on slope, soil conditions, and distance from a stream can be overlayed to determine land most suitable for development and land that should be preserved for environmental protection.

GISs help users to study and synthesize the factors contributing to sprawl in a particular community and identify potential solutions. Data from numerous departments, such as land-use planning, transportation, and economic development, can be pulled together, trends and interactions can be analyzed and visualized, and, as a result, better decisions can be made. For example, data such as the primary land uses of an area can be combined with the existing and planned major roads and highways and the planned residential and commercial developments to project how much open space will be lost, how much traffic will increase, and where more development will likely occur. A number of models featured in this guide are linked to GISs, enabling improved spatial analysis and the ability to map trends and projections.

Exhibit 3-1. Layers of a GIS



A GIS is composed of numerous digital maps that display information on various characteristics of the region under study. These maps, also called layers, coverages, or themes, are layered one on top of the other according to precise location references common to each map (see Exhibit 3-1 for a regional-scale example). These layers, in turn, are linked to data tables of additional information about a particular map feature, be it a street, ZIP Code, or census tract. Information displayed on different layers can be compared and analyzed in combination. A user can zoom in on a particular area and cut the desired location from all layers in the system. The power of a GIS lies in this ability to separate information in layers and combine it with other layers of information to support decision making. Thus, a GIS is much more than a software application; it is a decision-support *process* (Foote and Lynch, 1997).

Many modern GIS software packages offer user-friendly, Windows-based environments. Among the software packages popular with planning professionals are Atlas GIS, MapInfo, and Environmental Systems Research Institute, Inc.'s ArcView and ArcInfo GIS. Courses in GIS are widely available at universities and community colleges across the country.

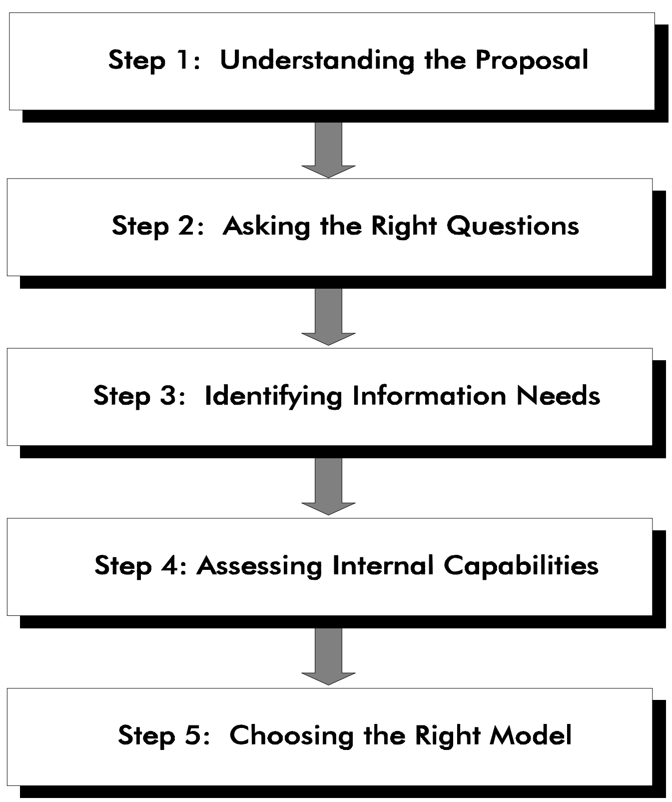
3.3 Integrated Planning and Decision-Making Systems

Integrated planning and decision-making systems (IPDMSs) promise to be the next state-of-the-art tool for modeling land-use change interactions. An IPDMS can pull together all of the modeling capabilities found in various models into one integrated modeling system. An integral part of the power of the IPDMSs is their employment of "expert systems." Expert systems are decision-support systems that model human reasoning by codifying the experience and judgment of experts and then programming a set of procedures that computers can execute when faced with relevant problems (Sumner, 1992). Thus, an IPDMS could combine travel demand, urban economic, and fiscal and environmental analysis into one powerful modeling system. Further, such a system could incorporate the mapping capabilities of a GIS to provide visual depictions of model results. Though an IPDMS that examines land use can not be identified at this time, it is conceivable that such a system could be developed to support a community's visioning and goal setting efforts, survey a community on visual preferences, identify and map community assets, and project future impacts to quality of life based on a range of potential development scenarios.

4.0 Selecting the Best Land-Use Model

There will be times when city or county planners, government officials, and concerned citizens will have to understand the complex issues surrounding development and growth in their community and make informed choices about which alternatives to pursue. The scenarios presented in Exhibits 4-2 through 4-4 depict some common situations communities are dealing with today. When faced with such situations–either as the decision-maker or one who seeks to inform or influence the decision-making process–it is worth considering the five-step approach to selecting the best land-use model illustrated in Exhibit 4-1. This approach begins by clearly defining the whole scenario involved in the decision making (e.g., a proposal for a new development project) and concludes with criteria for model selection. The appropriate model will vary from scenario to scenario and from community to community. The model needed today may be completely different than the model needed for tomorrow's project. This variation between projects requires an understanding of the diversity of models available in order to determine which is the best model to use in a given situation.

Exhibit 4-1. The Five-Step Process for Selecting a Land-Use Change Model



The most critical component of an effective community decision-making modeling tool is its ability to address specific analytical needs and to model alternative planning approaches. The model's competence in integrating and analyzing diverse data to quantify the benefits of a particular approach, followed by its ability to project the outcomes of that approach with the desired level of precision, are invaluable when trying to build community consensus, understand the costs and benefits of a proposed action, and move new plans toward implementation.

It is important to note that while current land-use change models serve as powerful tools to assist communities in making sound planning decisions, many are limited in their capabilities. Few, if any, attempt to fully model all of the various factors affecting land-development patterns, and none can account for *all* of the factors that affect land markets and travel behavior. Thus, no model can perfectly replicate reality. But, as technology continues to advance and land-use changes continue to be of concern, more–and better–models will be developed to answer the specific policy questions of citizens, land-use planners, and decision makers.

4.1 Step 1. Understanding the Proposal

The first step in selecting a model is comprehending the project's proposal. Is the consideration a new discount chain store that wants to locate on the edge of town? The impacts of expanding infrastructure to a new area? The consequences of a revised business tax strategy? Or the desire to preserve environmental resources? When reviewing the proposal, it is important to determine the project's entire geographic scope. What are the project's land boundaries? The proposal must be stated as succinctly, objectively, and as accurately as possible in order to begin the decision-making process. In addition, it is imperative that all involved decision-making parties have a common understanding of the proposal.

4.2 Step 2. Asking the Right Questions

Once the proposal has been clearly defined, the project scope must be broken down into detailed pieces. At this point, essential questions must be asked in order to have a complete understanding of the full costs and benefits of the proposal. Consideration of the direct and indirect, synergistic, and cumulative impacts the project will bring to the community is needed. The scenarios in Exhibits 4-2 though 4-4 list some of the land-use questions that should be considered, though the examples are far from complete. Each community's situation is unique, so the questions from project to project will be unique as well.

Exhibit 4-2. Opportunities for Employing Land-Use Change Modeling – Example 1

RURAL-EDGE Weighs Implications of a Proposed Indoor Shopping Mall

RURAL-EDGE, a community of 25,000 people nestled in the middle of a large county, is comprised primarily of choice agricultural land. The area is known for its apple industry and livestock production–most production occurs at farms of 50 to 500 acres throughout the county. RURAL-EDGE provides the industrial support to package and ship these agricultural products. Although located less than 120 miles from a major metropolitan area (i.e., an area exceeding 1 million people), RURAL-EDGE has managed to escape the dramatic population increases of communities closer in. Until recently, that is. Prior to 1990, RURAL-EDGE was connected to the metropolitan area by a single two-lane highway; however, in 1990, efforts to widen the existing highway were concluded and a new highway was constructed. RURAL-EDGE was now much more accessible, turning the rural area into a prime destination for urbanites who were seeking out rural life, not minding their longer commutes. Soon RURAL-EDGE began to be recognized as a hub city for the region. Local leaders began offering a range of incentives and subsidies to attract new business. Out-of-towners, in turn, began exploring land-investment opportunities. An entity from a neighboring state recently approached the city and county planners with a proposal to build a large indoor shopping mall at the interchange of the new roads. Affiliated with the shopping mall would be a telecommuting center for area workers.

Currently, the city and county planners are under pressure by government leaders to endorse the development proposal because they believe it will bring needed jobs and revenues to the area. Several local citizen groups are opposed, citing increased traffic congestion, loss of important historic and environmental resources, and an overall economic cost for the area. The citizen groups are threatening to sue if the project moves forward. The city and county planners know they need to weigh clearly all of the direct and indirect costs and benefits of the proposal, and have the data to do so. They also realize that they need some sort of tool to integrate and analyze all of the information so it makes sense. They believe that a land-use change model will provide the kind of integrative analytical tool that will help them answer some of the following questions:

- How much land will the project consume?
- Will the project convert existing commercial and retail land uses, or will it consume existing open space?
- Will prime agricultural land or other sensitive areas be lost due to the construction of this project?
- How many people will the project attract as shoppers and telecommuters? How many jobs will the project create? Where will these people come from? Will additional land uses need to be modified to accommodate the flow of traffic and the anticipated number of shoppers, new residents, and employees?
- What are the potential indirect land-use changes as a result of the project?
    - Will existing roads need to be widened or new roads built?
    - Will additional housing need to be constructed?
    - Will the project encourage other new businesses?
- What other land-use changes will be encouraged as a result of this project?
- Will this project have a negative effect on other parts of the community? For example, will the project shift activities (e.g., shopping, housing) from one part of the area to another?
- Will the project affect the amount of undisturbed open space and available parks?

Exhibit 4-3. Opportunities for Employing Land-Use Change Modeling – Example 2

METROBIG Weighs Transportation Alternatives' Effects on Community Land-Use Pattern

METROBIG is a large U.S. city that has enjoyed substantial prosperity and economic growth due to a booming high-technology industry. Unemployment is at an all-time low, out migration from the central city has slowed, and an improved tax base has given local decision makers a bit more spending flexibility. But with this economic development success has come relentless traffic congestion. The population has grown 20 percent in the last decade, while the acreage dedicated to urban uses has grown three times the population growth during the same period of time. Transportation system capacity has grown a mere 8 percent, frustrating commuters on a daily basis. Citizens are demanding solutions to gridlock. Some rally behind increased investment in roadway expansion, while others protest any transportation project that is not commuter rail.

Getting citizens and their elected officials to come to agreement on where to direct limited public resources in addressing transportation alternatives is no small matter given the fact that METROBIG's land area traverses two states and a number of local jurisdictions. Planners from a regional planning organization believe that integrated transportation and land-use modeling may help the localities reach consensus on regional planning goals and the joint implementation steps that must be taken for sound land-use planning.

At a recent series of vision-planning workshops, community members identified potential solutions. Regional planners are searching for the right land-use modeling tools that will help them determine the best mix of these potential planning options and answer the following questions:

- What impact would increasing the roadway capacity by half on the city's beltway have on land markets inside and outside the beltway? Would this increased capacity meet capacity needs 20 years into the future or would the investment merely induce demand and lead to similar gridlock?
- What impact would a circumferential rail transit around the beltway have on land markets inside and outside the beltway? Would this investment meet the travel demands?
- How do these two transportation investments compare in terms of overall induced land consumption and impacts on air and water quality?
- How will the opening of a new commuter rail station in the central city affect land markets?
- If traffic congestion becomes so bad in the outer suburbs that lack sufficient transit service, will people move back to the central city and inner suburbs? What impact will there be on these land markets?
- What impact will there be in terms of traffic movement and land markets should congested streets be replaced by tree-lined boulevards with fewer traffic lights?
- Can the use of public dollars toward central city home-ownership tax credits further reverse population decline and bring more families and jobs back to the city?

Exhibit 4-4. Opportunities for Employing Land-Use Change Modeling – Example 3

WISETOWN Plans Future Development

WISETOWN is located in a beautiful mountain valley along the banks of a pristine river. Since its settlement in 1802, it has been an important tourist destination. In addition to its natural beauty, it is filled with important historic sites associated with the town's popularity as a mountain spa and ski area. The town has quite a few historic hotels, churches, spa-related structures, and a railroad depot.

Population pressures from neighboring jurisdictions and increased access provided by several new roads and a small airport have begun to threaten the special character of WISETOWN. Recognizing the importance of maintaining its tourist attractions and the qualities that draw visitors, the WISETOWN mayor recently convened a community-wide visioning meeting. As a result of this three-day workshop, WISETOWN community members and leaders prepared a strategic plan that outlined areas they wanted to preserve from development. Participants identified historic sites, cultural attributes, and special environmental areas.

To implement the plan and to provide improved guidance for future development, community leaders need to take the results of the planning and visioning exercise and organize them to support future analyses. These leaders are interested in finding a tool that will help them with this effort. They hear that there are land-use change models that may help them accomplish their goals and answer the following questions:

- Where are our precious community resources located?
- Given that we want to preserve wetlands, forested slopes, riparian buffer strips, and flood plain areas, what land is left for development?
- Of the remaining land, what parcels should be set aside because they contain a historically–or culturally–important resource?
- Where are our steep slopes, loose soils, and otherwise non-buildable lands located?
- How will a proposed development affect the areas that have been set apart from development?
- What is the proximity of a proposed project to a protected area?
- Where are the best places to locate future development?

4.3 Step 3. Identifying Information Needs

Once the questions are formulated in step 2, a determination should be made as to what types of data are needed to answer the questions. If one question is where to locate a proposed project to minimize impacts on sensitive environmental areas, information is needed on where those areas are. If another question is the potential consequences of a new mall on surrounding land uses, information may be needed on trends from similar projects, projections on the number of shoppers and employees, and estimates of potential daily traffic. At this stage, it may not be possible to identify all of the informational needs (some answers will come after a decision has been made as to which model to use), but the process of identifying how well internal capabilities can find answers to the questions should begin.

4.4 Step 4. Assessing Internal Capabilities

The next step in selecting a model requires a clear understanding of what internal capabilities can be accessed to acquire and use the model. This includes assessing the following:

- ***Financial resources***. How much can be afforded?

- ***Staff resources***. What is the extent and talent of staff available to use the tool? Does additional help or consulting expertise need to be hired?

- ***Computer resources***. Do the proper hardware, software, and computing power resources exist on-site to run models?

It is important to be realistic in this assessment since a shortage of resources could result in ineffective installation and maintenance of the modeling tool–essentially rendering it useless.

4.5 Step 5. Choosing the Right Model (Using Selection Criteria)

Once the first four "background" steps have been completed, the final step is assessing and selecting the best model to meet identified needs. Before choosing, however, each option should be thoroughly analyzed against selection criteria. Thirteen primary selection criteria are provided and explained below as guidance. They are listed in an order that follows the likely thought process of a community that is considering a range of models. This is not an all-inclusive list of selection criteria. Other criteria may be important to consider based on the particular results of steps 1 through 4. The criteria may be weighted, based on level of importance, to guide the decision-making process. See Exhibit 4-5, at the end of this section, for an example approach to weighting the criteria.

- ***Relevancy.*** Does the model provide pertinent information that meets the analytical needs of the community?

  For a land-use model to be relevant and of value to a community, it must be able to model and project outcomes for scenarios that relate to the community and its needs. The first step in determining the relevancy of a model to community needs is to ask which land-use change will be evaluated by the study. Keep in mind that some models can evaluate several different types of land-use changes, while other models are limited to only one or two types.

  The next step is to carefully identify the questions or issues that will be addressed by the study. Careful definition of the questions is essential in determining the boundaries of a study (e.g., topical, spatial, temporal) and the general types of information required to run the model. Every attempt should be made to break the larger questions into smaller, more quantifiable ones. Supporting documentation on the model, as well as a detailed description of the model's data output, should provide the necessary information to determine if the model can answer the questions. It may be helpful to review the data outputs and capabilities of various land-use models in order to better identify and clarify the types of questions for potential evaluation.

- ***Resources.*** Are the model and the computer requirements (hardware, software) and staff (number of people and their time) needed to support the system within the community's budget and infrastructure?

  The resources required to use a model include cost of the model and associated computer requirements and the staff time to implement the model. To determine the full cost of a model, conduct an accurate accounting of the associated costs needed to acquire and maintain the model, measured in both dollars and time. Consider the purchase price of the model, as well as any additional hardware and software computer requirements needed to support the model. Also consider any long-term maintenance costs associated with the use of the model and associated computer resources.

  It is important also to factor in the amount of time and labor needed to run the model. Some models require full-time attention from dedicated staff and/or consultants, while others provide more user-friendly software tools that someone with minimal experience can run from a desktop computer. If the staff involved in the project are not volunteers, then their salaries, or the appropriate percentage of their salary based on anticipated labor hours needed to perform the study, should be incorporated into the overall operating costs of the model. In addition to any staff that may be supervising or supporting the study, expert consultants may be required to run the model and interpret the results, depending on the complexity of the model chosen. If an outside consultant is required, these additional consulting fees must also be added to the cost of the model.

  Finally, when considering cost, it is necessary to evaluate whether it would be more cost-efficient to hire an outside consulting firm to perform the study than to purchase the model. Government agencies may be able to save money by seeking assistance from another agency with adequate resources. In general, the more sophisticated a model is, the more expensive it is to obtain, tailor to local conditions, and operate. In any proposed project, the cost of the models used must be weighed against the level of precision necessary to meet the project's objectives. If the types of analyses desired are needed on a regular basis, it may be most worthwhile to purchase the model and its components and hire skilled operators as permanent in-house technical staff.

- ***Model Support.*** Do the model developers, or does the model itself, provide sufficient support needed to understand and implement the model (e.g., model documentation, user discussion groups, training)?

  Computer models, like any other computer hardware or software products, often have varying levels of support for end-users. Typically, models offer documentation and a user's guide to help understand how to load and run the model. Other levels of service also may be offered, including the potential to join users' groups, take workshops or electronic tutorials, view an Internet web site for additional information, and contact help lines. A careful assessment of in-house capabilities is needed to determine which kind of model support would be necessary. Depending on the outcome of such an assessment, this could be an important criterion for consideration.

- ***Technical Expertise.*** Does the community have the technical expertise required to use, calibrate, and interpret the results of the model?

  In general, the more sophisticated a model is, the more technical expertise will be required to operate the model and interpret the results. An expensive, complex, sophisticated model is of no value to the community if the community lacks the ability to use the model or understand its data output. Before selecting a model, a community must understand the level of technical expertise required to maintain and operate the model in order to determine if the model can be maintained in house or if the services of a consultant will be needed.

- ***Data Requirements.*** Does the community have, or can they obtain, the data necessary to run the model?

  Many land-use change models are data intensive and/or require a certain scale of data to provide reliable results. For example, a model may require that land-use data be on a scale that can be provided only by aerial photography, not satellite imagery. Some models operate best with locally-based data inputs. Unfortunately, much available data are aggregated to a county, regional, or larger area. Disaggregation of such data may be impossible and/or severely compromise data quality. Collection of local data may require a significant resource commitment. In some instances, the necessary temporal scale of data is not available. It is important to conduct a realistic assessment of existing data resources (including time period, and spatial coverage and resolution) and/or a user's ability to collect new data. Always remember that the selected model will be constrained by the data available.

- ***Accuracy.*** Are the projections generated by the model reliable to a degree that is useful to the community?

  The term "accuracy" can be interpreted in different ways. In general, it refers to how close the model comes to reality, and how well the model answers the questions posed. Complex models usually take into account more variables (i.e., they contain a greater level of detail) and, therefore, can provide more specific results and can more successfully simulate true conditions than simplified models that rely on many averages and assumptions. Accuracy also involves the "goodness-of-fit" of model results when compared against known outcomes of given scenarios. Some model developers have conducted accuracy analyses by "back-casting" projections through a recent historical period, and comparing the results with what actually transpired. The more important that known accuracy is to a study, the more advisable it is to use a model where goodness of fit has been evaluated.

Additional factors for consideration include the *resolution* and the *temporal capability* of the model (see below). The more accurate a model is, the more useful the results and potentially the more defensible if challenged. When a model is intended to provide the basis for key land use policies and decisions that may greatly impact citizens or businesses, the user should take accuracy into consideration to evaluate whether the model results could withstand challenges by affected community members.

- ***Resolution.*** What amount of land and what level of detail can be modeled in a single scenario?

  Resolution refers to the minimum unit of land that the model recognizes in its functions. Some models can simulate land use down to the parcel level, while others may be limited to larger areas (e.g., larger than a certain number of acres, full city- or county-level). High resolution (e.g., square feet) is useful when the study area is small and generalizations or averages would render differences between land areas within the overall study with less clarity. Low resolution (e.g., acres) is useful when the study area is large, averages would provide adequate information, and collection of highly detailed data would create a volume of information so large that it would impede a thorough analysis.

- ***Temporal Capabilities.*** Can the model project outcomes for multiple time periods?

  When evaluating a model, it is important to determine the level of flexibility a model provides in temporal resolution and extent. The term *temporal capabilities* refers to the time periods the model examines and the length of each of these time periods. For example, a model may project housing needs for the next 50 years, breaking the results down by 10-year increments. In some models, these time periods may be fixed. If there is a need to examine trends over different time periods and at different intervals, this type of model probably is not best.

- ***Versatility.*** Can the model project outcomes for multiple variables (i.e., land use, transportation, employment, housing, and environmental)?

  The versatility of a model refers to the model's ability to evaluate, integrate, and link multiple variables such as land use, transportation, employment, and housing. Consider versatility once it is clear how complex the proposal is that is being evaluated. Generally, the more versatile a model is, the more complicated it is. As a model becomes more complex, the data requirements and technical expertise needed to operate the model increase. When selecting a model, it is necessary to be aware of the types of issues that need to be evaluated and the cost-effectiveness of investing in a model that can evaluate multiple variables. When looking at the versatility of a model, it is important to consider two fundamental selection criteria: *relevancy* and *cost*.

- ***Linkage Potential.*** Can the model be linked to other models currently in use by, or of interest to, the community?

The linkage potential of a model refers to the ability of a model to join with other tools, including geographic information systems (GISs), other models, or presentation software. A model with high linkage potential is desirable, since it allows the user to connect the data outputs to other software that could help further analyze and/or present the information in a different or more useful way. To date, no single model exists that can perform all community planning functions; it is very likely that it will be necessary to link economic, transportation, and land use models together, then visualize the results by incorporating the output into a GIS.

- ***Public Accessibility.*** Can the model be run in an interactive public environment and display the results in a manner that is comprehensible to the general public?

  A model is publicly accessible if it can be approached and understood by the general public. If data output is presented in an easy-to-comprehend manner, such as a graph or bar chart, the results can reach a wider audience. Using a model in a public forum or meeting to demonstrate the outcomes of different scenarios can be a powerful way to educate the public and generate support for a proposed policy or plan.

- ***Transferability.*** Can the model be applied to locations other than the one(s) for which it was developed?

  A model may have been designed for a particular location, and therefore may require intensive efforts to adapt it for use in another. Site-specific information that may require modification includes land use, environmental, and economic policies; land-use categories; available data and resources; time periods; and spatial extent (e.g., regional, local, neighborhood). The type of information that can or must be changed will depend on the model, as will the level of effort necessary to make the changes, such as having to re-calibrate underlying statistical equations, change input parameters, and modify model assumptions. Such efforts can be costly due to the time and the technical expertise required for each adaptation. If resources are minimal, it is wise to select a model that can be easily transferred. For several land use models, the technical fact sheets in Appendix B provide details on the efforts (reflected in the pre-processing, calibration, assumptions, and setting parameters information) required for adaptation to a new locale.

- ***Third-Party Use.*** How extensively has this model been used in “real-world” situations?

  Some land-use change models are under development, or have been used primarily in academic settings, while others have been used more extensively in community settings. A model used in a community setting, however, does not necessarily mean that the model is better than one with more limited use; one should carefully consider all the selection criteria to select the best model. Usually, it is best to select a model with a proven track record, especially if it has been used for communities having a similar size or similar situations. Also, if a model has been used extensively, there should be documented case studies about the efficacy of the model and opportunities to consult with end-users.

Exhibit 4-5. Example Criteria Rating Table

Criteria	Weight[1] (W)	Rating Score: (RS) 10 = High Match, 1 = Low Match — Alternatives: Model #1		Model #2		Model #3	
		RS	RS x W	RS	RS x W	RS	RS x W
Relevancy							
Resources							
Model Support							
Technical Expertise							
Data Requirements							
Accuracy							
Resolution							
Temporal Capabilities							
Versatility							
Linkage Potential							
Public Accessibility							
Transferability							
Third-Party Use							
Total Score							

[1] Weights may be numeric (e.g., 1=low weight, 5=high weight) or qualitative (e.g., low, medium, high). A numeric weight enables users to multiply the weight and the rating score to determine a numeric value for each model. For example, if relevancy was given a weight of “5" and Model 1 scored a 2 for a rating, Model 2 scored 5 and Model 3 scored 10, their respective numeric totals would be 10, 25, and 50. Clearly, Model 3 is best for relevancy. After all criteria are applied, the total scores for each model are tallied.

Source: Adapted from Chang and Kelly, 1995.

5.0 Summarizing the Land-Use Models

Given the variety and scope of land-use models, finding and sorting through information and identifying a model can be a daunting task. To make the task more manageable, this guide provides summary information on 22 leading land-use change models (see Exhibit 5.1). The goal of the summary information is to enable a sufficiently clear and thorough understanding of the models to allow readers to make an informed selection of the model that is most appropriate for their particular resources and needs.

The models are summarized in this guide in four ways:

- **Key selection criteria** (see Section 5.2).
  The models are sorted and listed in tables according to a few key selection criteria.

- **General fact sheets** (see Section 5.3).
  The general fact sheets provide a brief but thorough overview of the fundamental features of each model. See Section 5.3 for more details on the particular features covered.

- **Comparative matrices** (see Appendix A).
  The comparative matrices include for each model selected information from the general and technical fact sheets, as well as some additional information not found in the fact sheets, in a format that allows for quick comparisons between the models.

- **Technical fact sheets** (see Appendix B).
  The more technical information for each model is provided in these fact sheets, including the geographic and temporal scale of the model, model assumptions, parameters, post-processing requirements, and the next steps for development.

The information contained in the fact sheets and matrices is based on reference materials and model developer reviews, not on direct use and experience with the models. All information was verified by the model developers or representatives of the developers.

5.1 Developing This Summary

EPA's first step in developing this inventory of land-use change models was to convene a workgroup comprising academic modelers and federal staff who serve as community liaisons. This workgroup framed the guide's content and format according to perceived user needs. EPA then contracted with Science Applications International Corporation (SAIC) to collect appropriate information and compile the findings. Using the workgroup's list of 14 model features for characterization, SAIC developed a standard work sheet to examine identified models. Model features researched by SAIC included the following:

- Model name
- Contact information for the model developer
- Description
- Resource requirements
- Theoretical framework
- Data inputs
- Model outputs
- Strengths
- Limitations
- Required expertise
- Geographic and temporal scale
- Transferability to multiple locations
- Capability of linking with other models
- Gaps that need to be addressed.

SAIC conducted independent research on these factors using journal publications, Internet web sites, user's guides, and demonstration models. Researchers used information collected from these sources to complete a summary worksheet for each model. These worksheets formed the basis for the narrative fact sheets (both general and technical) and comparative matrices found in this guide.

Upon completion, SAIC provided the worksheets and fact sheets to the model developers, or appropriate designated colleagues, for verification of technical accuracy and supplemental information. All information on models presented in this guide was subject to this review process and was approved by the model developers.

Exhibit 5-1. Land-Use Change Models Included in This Guide

Model	Developer	Purpose
California Urban Futures (CUF) Model: CUF-1	John Landis, Institute of Urban and Regional Planning, University of California at Berkeley	Provides a framework for simulating how growth and development policies might alter the location, pattern, and intensity of urban development
California Urban Futures (CUF) Model: CUF-2	John Landis, Institute of Urban and Regional Planning, University of California at Berkeley	Same as CUF-1 (CUF-2 addressed some of the theoretical holes of CUF-1)
California Urban and Biodiversity Analysis Model (CURBA)	John Landis, Institute of Urban and Regional Planning, University of California at Berkeley	Evaluates the possible effects of alternative urban growth patterns and policies on biodiversity and natural habitat quality
DELTA (formally DSCMODE)	David Simmonds Consultancy	Projects changes in urban areas, including the location of households, population, employment, and the amount of real estate development
Disaggregated Residential Allocation Model of Household Location and the Employment Allocation Model (DRAM/EMPAL)	S.H. Putman and Associates, Inc.	Projects the interactions and distribution of employment and housing in a specified geographic area
Growth Simulation Model (GSM)	Maryland Department of Planning, Baltimore, Maryland. Contact: Joe Tassone	Projects population growth and new development effects on land use/land cover under alternative land management
INDEX®	Criterion Planners/Engineers, Inc.	Measures the characteristics and performance of land-use plans and urban designs with "indicators" derived from community goals and policies
IRPUD Model (formally Dortmund)	Michael Wegener, Institute of Spatial Planning, University of Dortmund, Germany	Projects the impacts of long-range economic and technological change on housing, transportation, public policies, land uses, and infrastructure
Land Transformation Model (LTM)	Dr. Bryan C. Pijanowski, Michigan State University	Integrates a variety of land use change driving variables to project impact on land use on a watershed level

Model	Developer	Purpose
Land-Use Change Analysis System (LUCAS)	Michael W. Berry, et al., Department of Computer Sciences, University of Tennessee	Examines the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability
Markov Model of Residential Vacancy Transfer	Philip Emmi and Lena Magnusson	Explores changes in demand for various types of residential housing within a community
MEPLAN	Marcial Echenique & Partners Limited. Contact: Ian Williams	Helps communities analyze the inter-related effects of land use and transportation and is designed to compare proposed plans/policies
METROSIM	Alex Anas & Associates	Uses an economic approach forecasting interdependent effects of transportation and land use systems and of land use and transport policies
Sub-Area Allocation Model-Improved Method (SAM-IM) (formally LAM)	Planning Technologies, LLC	Creates new land use scenarios that reflect alternative development concepts for the future
The SLEUTH Model (formally Clarke Cellular Automata)	Keith C. Clarke, Department of Geography, University of California at Santa Barbara	Projects urban growth and examines how new urban areas consume surrounding land and impact the natural environment
Smart Growth INDEX®	Criterion Planners/Engineers, Inc. (with Fehr & Peers Associates, Inc.)	Evaluates transportation and land-use alternatives and assesses their impact on travel demand, land consumption, housing and employment density, and pollution emissions
Smart Places	Electric Power Research Institute (EPRI). Contact: Paul Radcliffe	Assists communities in the simulation and evaluation of land-use development and transportation alternatives using indicators of environmental performance
TRANUS	Modelistica	Analyzes the effects of land-use and transportation policies or combinations of policies on the location of various activities and the land market
UGrow	Wilson W. Orr, Prescott College	Projects long-term changes to communities in response to changes in transportation and fiscal policies

Model	Developer	Purpose
UPLAN	Robert Johnston, Dept. of Environmental Science and Policy, University of California at Davis	Creates alternative development patterns in response to changes in development and fiscal scenarios
UrbanSim	Paul Waddell, Daniel J. Evans School of Public Affairs, University of Washington	Explores how the interactions between land use, transportation, and public policy shape a community's development trends and affect the natural environment
What if?	Dr. Richard E. Klosterman (as Community Analysis and Planning Systems, Inc)	Supports comprehensive community land-use planning in regard to determining land suitability for development, projecting future land-use demand, and providing the capability to allocate the demand to the most suitable location

5.2 Land Use Models: Identified by Key Selection Criteria

As discussed in Step 5 ("Choosing the Right Model") in Section 4.5, communities may use a range of selection criteria to use help them single out the model that will work best for them. This section highlights five key criteria that every community is likely to consider and identifies how each of the 22 land-use models included in this guide fit the criteria. Please note that the models are listed in alphabetical order, not ranked, and the sorting is based on the worksheet information as provided by the model developers.

In addition to the five criteria provided here, the comparative matrices in Appendix A provide several more categories of information for each model. Readers may use the matrices to sort and compare the models based on the categories of information that best address their particular needs.

Exhibit 5-2. Technical Expertise Needed to Use Model [1]

None	*Some* [2]	*Extensive* [3]
CURBA Markov METROSIM SAM-IM Smart Places UGrow	CUF-1 CUF-2 GSM MEPLAN SLEUTH Smart Growth INDEX® TRANUS UPLAN UrbanSim What if?	DELTA DRAM/EMPAL INDEX® IRPUD LTM LUCAS

[1] Once the model has been installed/developed.
[2] Requires land use planning experience.
[3] Requires land use modeling experience.

Exhibit 5-3. Purchase Cost [1]

Free	*$1 – 5,000*	*$5,001 – 10,000*	*$10,000+*	*Contact Developer* [4]
LTM LUCAS Markov SLEUTH Smart Growth INDEX® UGrow[2] UPLAN UrbanSim	What if?[3]	TRANUS	DRAM/EMPAL INDEX® MEPLAN METROSIM SAM-IM	CUF-1 CUF-2 CURBA DELTA GSM IRPUD Smart Places

[1] Does not include operating, maintenance, or training costs.
[2] Software is free but model developer must adapt model to fit particular community at a cost ranging from $30,000 – $200,000.
[3] Cost varies depending on whether for academic ($250) or professional ($2,495) single user. Academic and professional site licenses are available.
[4] Models in this category are not available for direct purchase; either they were developed in an academic context, for a particular situation, or are coupled with consulting services. For example, the CUF models were developed in an academic context and utilized for specific pilot studies. They may be available for application to other locales, but it is necessary to contact the model developer to ascertain how to make that happen. Other models, like DELTA, are part of a consulting service and unavailable for direct purchase–the affiliated consulting firm must be hired.

Exhibit 5-4. Existence of Model Support

Model	*Written Documentation*[1]	*Web Site*	*Training*
CUF-1	✓		
CUF-2	✓		
CURBA	✓		
DELTA	✓	✓	✓
DRAM/EMPAL	✓	✓	✓
GSM	✓		
INDEX®	✓	✓	
IRPUD	✓	✓	✓
LTM	✓	✓	✓
LUCAS	✓	✓	✓
Markov	✓		
MEPLAN	✓	✓	✓
METROSIM	✓		✓
SAM-IM	✓		✓
SLEUTH	✓	✓	
Smart Growth INDEX®	✓	✓	
Smart Places	✓	✓	
TRANUS[2]	✓	✓	✓
UGrow			✓
UPLAN	✓		
UrbanSim	✓	✓	
What if?	✓	✓	✓

[1] Refers to materials such as a user's manual, published articles, or fact sheets.
[2] Also has extensive e-mail support.

Exhibit 5-5. Ease of Transferring to Other Locations [1]

Effortless [2]	***Feasible*** [3]
METROSIM Smart Growth INDEX® TRANUS	CUF-1 CUF-2 CURBA DELTA DRAM/EMPAL GSM INDEX® IRPUD LTM LUCAS Markov MEPLAN SAM-IM SLEUTH Smart Places UGrow UPLAN UrbanSim What if?

[1] For a detailed explanation of this sorting criterion, see section 4.5.
[2] Requires no modifications in order to transfer.
[3] Requires some modifications in order to transfer.

Exhibit 5-6. How Many Locations Has the Model Been Applied To?

1–5	**6–10**	**11–20**	**20+**
CUF-1 CUF-2 IRPUD LTM LUCAS SAM-IM Smart Places[1] UPLAN UrbanSim What if?	CURBA DELTA METROSIM UGrow	INDEX® Markov SLEUTH Smart Growth INDEX®	DRAM/EMPAL GSM MEPLAN TRANUS

[1] At present, Smart Places has been applied only once but more than 35 communities have license agreements to use it.

5.3 Land Use Models: General Fact Sheets

The general fact sheets, provided alphabetically in this section, include essential information about each land-use change model, such as: model developer contact information, an overview of the capabilities of the model, the resources required to operate the model, land uses addressed by the model, the questions or issues the model can help assess, data inputs required by the model, outputs generated by the model, model strengths and limitations, model accessibility, and case study information. It is expected, in most cases, that the general fact sheets alone will provide enough information for readers to make a sound decision as to whether particular models may be useful to them.

The general fact sheets provide a starting point in investigations about appropriate models. The more technical information is included in Appendix B (intended primarily for those readers with modeling experience). After narrowing the choices, potential users should contact the developers for more complete and up-to-date information. In many cases, models are continuously being refined and improved, so it is important to seek the latest information on models of interest.

California Urban Futures (CUF) Model: CUF-1

MODEL DEVELOPER(S): John Landis, Ted Bradshaw, Ted Egan, Peter Hall, Ayse Pamuk, David Simpson, Qing Shen, Michael Teitz, and Ming Zhao.

MAILING ADDRESS: Institute of Urban and Regional Development
University of California at Berkeley
Berkeley, CA 94720-1879

CONTACT INFORMATION:
Phone: 510-642-5918
Fax: 510-643-9576
E-mail: jlandis@uclink.berkeley.edu

WEB SITE: http://www-dcrp.ced.berkeley.edu

DOCUMENTATION:

Landis, J. D. 1994. The California Urban Futures Model: A New Generation of Metropolitan Simulation Models. *Environment and Planning, B: Planning and Design*, 21: 399-420.

Landis, J. D. 1995. Imagining Land Use Futures: Applying the California Futures Model. *Journal of the American Planning Association*, 61: 438-457.

OVERVIEW

The California Urban Futures Model is known as the CUF Model or CUF-1 (earlier versions of the model were known as the Bay Area Simulation System [BASS II]). The purpose of the CUF-1 model is to provide a framework for simulating how growth and development policies might alter the location, pattern, and intensity of urban development. The model is designed to consider growth and development policies at various levels of government (e.g., state government, local government, and special districts). The model was originally developed to simulate the impacts of alternative regulatory and investment policy initiatives on urban development in the Northern California Bay Region. Note: CUF-1 has been superceded by CUF-2 and CURBA.

The CUF-1 model allows the user to:

- Project population growth at a sub-area level (e.g., a city) and then aggregate projected growth to larger units (e.g., a county),
- Allocate growth to individual sites based on development profitability,
- Incorporate several variables, including spatial accessibility, to determine the location and density of new development,
- Assemble, organize, manage, and display data describing land development options with geographic information systems (GIS),
- Incorporate development policies into the growth forecasting process, and
- Simulate new policy scenarios quickly and display results in easy to understand map forms with various levels of detail.

The CUF-1 model uses two primary units of analysis, political jurisdictions (incorporated cities or counties) and developable land units (i.e., undeveloped or underdeveloped areas that may be developed or redeveloped [DLUs]). First, the model projects population growth based on city population growth trends and development potential by DLU. The CUF-1 model then simulates growth of an area by determining how much new development to allocate to each DLU per model period based on population growth of each city or county, the profitability potential of each DLU if developed, and user-specified development regulations and/or incentives. This is accomplished using four related submodels: the bottom-up population growth submodel, a spatial database, the spatial allocation submodel, and the annexation-incorporation submodel.

REQUIRED RESOURCES

Purchase Costs
Not available for "off the shelf" purchase. Contact the model developer.

Equipment Needs
CUF-1 requires a UNIX-based workstation with a UNIX operating system, programming language compilers, and SPSS statistical analysis software.

Staff Requirements and Expertise
Installation and calibration of the model requires experience in SPSS and ArcInfo as well as land-use modeling expertise. Use of the model requires land-use expertise and general computer experience.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed
The land-use categories addressed by CUF-1 are user defined and, therefore, could include any land-use category as appropriate for the study area. Four major land-use categories were used for the CUF-1 San Francisco Bay and Sacramento areas simulation: agricultural land type, general plan use category, current land use, and wetlands.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial		
Mixed-Use		
Industrial		
Other		

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure		✔
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔[1]	
Local Government Fiscal Conditions	✔[1]	
Availability of Open Space	✔	
Environmental Quality	✔[2]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

[1] Only with some modifications or additions.
[2] For water quality, "yes" with some modifications or additions. For air quality, "no."

Outputs Provided

Output	Format
Quantitative outputs	Acreage tabulations and total
Graphical outputs	Maps of newly-developed areas

INFORMATION NEEDED TO RUN THE MODEL

This model requires the following user input:

- Multiple ArcInfo coverages or themes profiling existing land use, general plan, and environmental characteristics, as well as jurisdictional boundaries.

- Jurisdiction-level tabular information profiling historical population growth.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Easy to use and visual: The CUF-1 model allows users to prepare and evaluate alternative policy scenarios quickly (a typical simulation can be completed in a matter of hours) and in easy to read map form at almost any level of detail.

- Expandable: The CUF-1 model is designed as a modular system of related but independent submodels that can be updated to include new information and theories.

- Policy approach: The CUF-1 model simulates alternative development futures based on specific policy changes.

Limitations

{A second generation of the CUF model ("CUF-2") has been developed to address several of the limitations discovered in the original CUF-1 model.}

- Availability: The CUF-1 model is currently unavailable as a product that can be purchased "off the shelf."

- Singular land use: The CUF-1 model is limited to residential development and does not include methods for projecting and/or allocating future industrial, commercial, and public activities. Therefore, sites that are the most profitable to develop are reserved for residential development (unless explicitly prohibited).

- Lack of "infill" development and urban redevelopment: The CUF-1 model assumes that almost all population growth will occur at the urban edge.

- Growth allocation primarily depends calculated on development profitability: The CUF-1 model may be insensitive to other factors that impact growth patterns and locations (e.g., impacts of new infrastructure investments).

- Lack of integration of historical experiences: The CUF-1 model's rules for allocating future development were not calibrated against historical experience.

LEARNING MORE

Additional References

None.

Availability of Preview Copies of the Model

Potential users must contact the model developer.

Case Studies

Landis, J. D. 1995. "Imagining Land Use Futures: Applying the California Futures Model." *Journal of the American Planning Association*, 61: 438-457.

Application Sites

Northern California; Solano and Sonoma counties

California Urban Futures (CUF) Model Second Generation: CUF-2

MODEL DEVELOPER(S): John Landis

MAILING ADDRESS: Institute of Urban and Regional Development
University of California at Berkeley
Berkeley, CA 94720-1870

CONTACT INFORMATION: *Phone:* 510-642-5918
Fax: 510-643-9576
E-mail: jlandis@uclink.berkeley.edu

WEB SITE: http://www-dcrp.ced.berkeley.edu

DOCUMENTATION:

Landis, J. D. and M. Zhang. 1998. “The Second Generation of the California Urban Futures Model: Part I: Model Logic and Theory.” *Environment and Planning, B: Planning and Design*, 25: 657-666.

Landis J. D., M. Zhang, and M. Zook. 1998. *CUFII: The Second Generation of the California Urban Futures Model.* UC Transportation Center, University of California, Berkeley, CA.

OVERVIEW

The purpose of the California Urban Futures Model Second Generation (CUF-2) model, like the CUF-1 model, is to provide a framework for simulating how growth and development policies might alter the location, pattern, and intensity of urban development. (See the evaluation of the CUF-1 model for a more detailed description of the model’s intended use.) The second-generation was developed to address some of the theoretical holes of the first model.

The CUF-2 model performs many of the functions as the CUF-1 model (see the evaluation of the CUF-1 model). Several changes were made to the first generation, however. The following provides a brief description of each of the four main components of the CUF-2 model:

- The activity projection component uses a series of econometric models to project future population, households, and employment by jurisdiction at 10-year intervals. Although the future population and households are projected as they are in the CUF-1 model, the employment projection is a new component of CUF-2.

- The GIS based spatial database generates and updates the location and attributes of each developable land unit (DLU) and allows the user to visually display the spatial pattern of growth. In CUF-2, DLUs are one-hectare grid-cells, not (as in CUF-1) irregularly-shaped polygons.

- The land use change submodel is calibrated against historical urban land use changes Independent variables include: local population and employment growth; proximity to regional job centers; site slope; whether the site is within or beyond city boundaries or spheres of influence; the uses of surrounding sites; the availability of vacant land; site proximity to freeway interchanges and transit stations; and site proximity to major commercial, industrial, and public land uses.

- The model allows for spatial bidding for sites between four types of new development land uses and three types of redevelopment and use change submodel is calibrated against historical urban land use changes.

REQUIRED RESOURCES

Purchase Costs
Not available for “off the shelf” purchase.

Equipment Needs
CUF-2 requires a 300 MHz or higher PC or Sun Sparc computer with 32 MB of RAM, 2 GB of hard drive space, color monitor, Soloris and Windows 95 operating systems, SAS statistical analysis software, and ArcView or ArcInfo.

Staff Requirements and Expertise
Installation and calibration of the model requires experience in SAS and ArcInfo as well as land-use modeling expertise. Use of the model requires land-use expertise and general computer experience.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed
The land-use categories addressed by CUF-2 are user defined and, therefore, could include any land-use category as appropriate for the study area. Seven major land-use categories were used for the CUF-2 San Francisco Bay Area simulation: undeveloped, single-family residential, multi-family residential, commercial, industrial, transportation, and public.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔[1]	

[1] Only for developer impact fees (with modifications), and municipal sewer and water fees.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔[1]	
Local Government Fiscal Conditions	✔	
Availability of Open Space	✔	
Environmental Quality	✔[2]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

[1] Only if linked to a travel demand model.
[2] For water quality, "yes" potentially or if amended by the user. For air quality, "no."

Outputs Provided

Output	Format
Quantitative outputs	New development an redevelopment acreage total by land use type
Graphical outputs	Maps of existing and projected development (by land use type)

INFORMATION NEEDED TO RUN THE MODEL

This model requires the following user inputs:

- Hectare-scale digital maps of urban land uses at two or more points in time.
- Multiple ArcInfo coverages or themes profiling existing land uses, general plan, and environmental characteristics, as well as jurisdictional boundaries.
- Jurisdiction-level tabular information profiling historical population growth.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Easy to use and visual: The CUF-2 model allows users to prepare and evaluate alternative policy scenarios quickly (a typical simulation can be completed in a matter of hours) and in easy to read map form at almost any level of spatial detail.

- Expandable: The CUF-2 model is designed as a modular system of related but independent submodels that can be updated to include new information and theories.

- Policy approach: The CUF-2 model simulates alternative development futures based on specific policy changes.

- Calibrated to past local experience.

Limitations

- Availability: The CUF-2 model is currently unavailable as a product that can be purchased "off the shelf."

- Data intensive: The CUF-2 model requires much more data than the original CUF-1 model.

- Model calibration requires detailed knowledge of statistics. Results can be spatially auto-correlated.

LEARNING MORE

Additional References

Landis, J. D. 1995. Imagining Land Use Futures: Applying the California Futures Model. *Journal of the American Planning Association*, 61: 438-457.

Landis, J. D. 1994. The California Urban Futures Model: A New Generation of Metropolitan Simulation Models. *Environment and Planning, B: Planning and Design*, 21: 399-420.

Availability of Preview Copies of the Model

Potential users must contact the model developer.

Case Studies

For more information contact the model developer.

Application Sites

San Francisco, CA Bay Region.

California Urban and Biodiversity Analysis Model (CURBA)

MODEL DEVELOPER(S): John Landis, Michael Reilly, Pablo Monzon, and Chris Cogan.

MAILING ADDRESS: Institute of Urban and Regional Development
University of California at Berkeley
Berkeley, CA 94720-1870

CONTACT INFORMATION:
Phone: 510-642-5918
Fax: 510-643-9576
E-mail: jlandis@uclink.berkeley.edu

WEB SITE: http://www-dcrp.ced.berkeley.edu

DOCUMENTATION: *Development and Pilot Application of the California Urban and Biodiversity Analysis (CURBA) Model*. University of California at Berkeley. September 1998.

OVERVIEW

The CURBA model was developed as a tool to help urban planners to evaluate the possible effects of alternative urban growth patterns and policies on biodiversity and natural habitat quality. CURBA can help direct urban growth while promoting environmental and ecological quality.

The CURBA model consists of two major components, an Urban Growth Model and a Policy Simulation and Evaluation Model. The Urban Growth Model assists the user in calibrating equations that describe past urbanization patterns and applying the equations to project future development patterns. The Policy Simulation and Evaluation Model projects how alternative development policies will affect future urbanization patterns and the associated impacts on habitat integrity. For example, CURBA can help users investigate the effects of urban growth on vegetation land cover by type, habitat for various species (e.g., different mammals, reptiles, and birds), changes in the level of fragmentation, etc. The CURBA model is used in conjunction with ArcView and various Avenue scripts.

REQUIRED RESOURCES

Purchase Costs
Contact the model developer.

Equipment Needs
CURBA requires a 300 MHz or higher PC with 32 MB of RAM, 300 MB of hard drive space, color monitor, Windows operating system, SAS or SPSS statistical analysis software, and the ERSI ArcView Geographic Information System.

Staff Requirements and Expertise
Installation and calibration of the model requires experience in ArcView and land-use modeling expertise. Use of the model requires no land-use expertise, but does require familiarity with ArcView, SAS, or SPSS.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed
The pilot simulation used the following categories: urban (does not differentiate between commercial, industrial, and other urban land use types), vegetation types (from GAP datasets), agricultural lands, and other landscape and infrastructure data. These categories are from the California Farmland Mapping and Monitoring Project (FMMP).

Urban Land-Use Categories	Yes?	No?
Residential		✔
Commercial		✔
Mixed-Use		✔
Industrial		✔
Other		✔

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered
(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔[1]	
Local Zoning	✔[1]	
City/County Master Plans	✔[1]	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

[1] With calibration.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Bio-diversity and Habitat Quality	✔	
Environmental Quality	✔	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

Note: CURBA can evaluate potential impacts of land use changes on habitat types and species that are reliant on these habitats.

Outputs Provided

Output	Format
Evaluation results predicting the impacts of projected urban growth on various habitat types	Maps and tabular summaries
ESRI "shape files" displayed as bit-mapped images and graphical displays of analysis results	Polygon and grid files

INFORMATION NEEDED TO RUN THE MODEL

Inputs will depend on the goals and objectives of the user. Typically, the more detailed inputs the user can provide, the more in-depth analyses can be performed. The following user input was used for the pilot simulations:

- Land use types from the California Farmland Mapping and Monitoring Project (FMMP) database (ArcView coverages). [Note: Certain data may require reformatting to accommodate the GIS.]
- First and second generation GAP Analysis data, including ecoregions, vegetation classification zones, and vertebrate species habitat.
- Slope and elevation data from the USGS Digital Elevation Model.
- Locations of roads, hydrographic line features, and major water bodies (Census Bureau TIGER files).
- Jurisdictional boundaries (Census Bureau TIGER files).

- Wetlands and vernal pools from the National Wetlands Inventory. Various socioeconomic data (e.g., population and employment levels). FEMA Q3 Floodzones.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Easy to access and use: Once calibrated, CURBA is run entirely in ArcView and can be used on a desktop computer. Base data are entirely in the public domain. It is also fast and flexible.

- Reveals trends and patterns: CURBA allows stakeholders to better understand the drivers of recent urbanization trends and patterns.

- Projective: CURBA allows users to project future urban growth patterns, the sensitivity of urban growth to alternative regulatory and environmental policies, and the effects of projected growth on habitat integrity and quality.

Limitations

- Future projected based on past: CURBA's results are reliant on how well the Urban Growth Model equations explain historical growth patterns and the extent that the factors that drove these patterns direct future development.

- All urban growth is equal: CURBA treats all urban developments the same and does not allow for the possibility of redevelopment. Also, CURBA assumes that all forms and patterns of urban growth represent the same level of habitat decline.

LEARNING MORE

Additional References
Not provided.

Availability of Preview Copies of the Model
Potential users must contact the developer.

Case Studies
Three environmental conservation scenarios for nine California counties (see Development and Pilot Application of the California Urban and Biodiversity Analysis (CURBA) Model. University of California at Berkeley. September, 1998.

Application Sites
Nine California counties:

- El Dorado
- Monterey
- Nevada
- Placer
- Sacramento
- San Joquin
- Santa Cruz
- Sonoma
- Stanislaus

DELTA

MODEL DEVELOPER(S): David Simmonds Consultancy

MAILING ADDRESS: 10 Jesus Lane
Cambridge CB5 8BA
England

CONTACT INFORMATION: *Phone:* +44 (0) 1223 316098
Fax: +44 (0) 1223 313893
E-mail: dsc@davidsimmonds.com

WEB SITE: http://www.davidsimmonds.com/land-use.html

DOCUMENTATION: Available from the model developer.

OVERVIEW

The DELTA model projects changes in urban areas, including changes in the location of households, population, employment and the amount of real estate development. Typically DELTA is set up to interact with a transport model. With a transport model, DELTA projects changes in land use that affect the demand for transportation and the impact of changes in accessibility on a variety of factors, including the location of different activities (e.g., households, employment) and the value of buildings. An optional regional level can be added within DELTA to model the regional economy and migration between urban areas.

REQUIRED RESOURCES

Purchase Costs

DELTA software currently is not available for purchase off-the-shelf as a self-contained software package. It is included as a component of overall consulting services provided by the model developer. The price of overall consulting services is set on a project-by-project basis depending on several factors, including the needs of the client, the size of the study area, and the amount and condition of the data available for incorporation into the system.

Equipment Needs

DELTA requires an IBM (or compatible) Pentium 200 MHz computer, MS DOS run either from DOS mode or under Windows 95/98, and DBOS memory manager (distributed with DELTA model). The model developer also recommends the use of spreadsheets, databases, and geographic information system (e.g., MapInfo) to prepare the data needed to run the model and to analyze the data obtained from the model. A color monitor is recommended.

Staff Requirements and Expertise

The consulting services of the model developer are required to use DELTA.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural		✔
Forest		✔
Wetlands		✔
Water		✔
Preservation		✔
Park Land		✔

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔[1]	
Local Government Fiscal Conditions		✔
Availability of Open Space		✔
Environmental Quality	✔[1]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions	✔	

[1] When DELTA is integrated with transport and environmental models.

Outputs Provided

The outputs provided by DELTA are the same type of data used to run the model (i.e., forecasts of numbers of households by type and location, jobs by sector and location, floorspace by category and location, etc.), although the data are updated as a result of running the model. DELTA is capable of producing output files that can be passed through Windows-based tools. The outputs should be loaded into a spreadsheet, database, and/or mapping software for analysis.

INFORMATION NEEDED TO RUN THE MODEL

DELTA was designed to be flexible to meet the needs of the user; therefore, it does not have rigid input requirements. The inputs required to operate the model are user defined, allowing the user to alter the inputs for each run of the model. DELTA is both an urban and a regional model. The DELTA urban model contains six sub-models that address the development process, demographic change (e.g., household formation) and economic growth, location and relocation of households and jobs in the property market, car-ownership choices, changes in employment status (working/non-working) and commuting patterns, and changes in the quality of residential areas. The DELTA regional model contains an additional three models for migration between different urban areas, the location of investment/disinvestment, and the pattern of production and trade.

The inputs to the DELTA urban and/or regional models include fixed-format ASCII files containing information on the location of households and jobs, car ownership levels, and floorspace supply and rent for a base year and pre-base years. In addition, the user should provide variables that define the economic and demographic scenarios to be modeled and coefficients to describe the behavior of households, businesses, developers, etc. (e.g., sensitivity of developers' location decisions to expected profitability, sensitivity of households' location decisions to rent, the quality of residential areas, etc.).

MODEL STRENGTHS AND LIMITATIONS

Strengths

- The DELTA model is unique in its ability to forecast changes over a series of short periods. This allows the user to prepare and evaluate future planning and development.

- The DELTA model allows the user to incorporate information to generate specific conditions into the model.

- The DELTA model provides an integrated software package that can be used as a stand alone package or could be set up to interact with a wide range of transport models.

Limitations

- The DELTA model currently is unavailable as an off-the-shelf product. Licensing for this model is on a project specific basis, and include the services of the model developer

LEARNING MORE

Additional References

Simmonds, D.C. "The design of the DELTA land-use modeling package." *Environment and Planning, B: Planning and Design.* Volume 26, pages 665-684. March 1999.

Simmonds, D.C. and Still, Ben. "DELTA/START: Adding Land Use Analysis to Integrated Transport Models." Paper presented to World Conference on Transport Research, Antwerp, 1998. "Selected proceedings of the 8th world conference on transport procedures." Volume 4. Pergamon, an imprint of Elsevier Science. 1999.

Availability of Preview Copies of the Model

Not available.

Case Studies

Case study information is available from the model developer. Brief overviews of where the model developer created both urban and regional DELTA applications can be found on the developer's web site.

Application Sites

- Greater Manchester and the Trans-Pennine Corridor, England
- Edinburgh, Scotland
- Yorkshire, England *(in development)*
- Sardina, Italy *(in development)*
- Uruguay *(in development)*

DRAM/EMPAL

(Other names: DRAM/EMPAL was part of ITLUP (Integrated Transportation and Land Use Package); now it is part of METROPILUS.)

MODEL DEVELOPER(S): S.H. Putman and Associates, Inc.

MAILING ADDRESS: 128 Deakyneville Road
Townsend, DE 19734-9751

CONTACT INFORMATION:
Phone: (302) 659-3263
Fax: (302) 659-3264
E-mail: putman@pobox.upenn.edu

WEB SITE: http://dolphin.upenn.edu/~yongmin/intro.html

DOCUMENTATION: A user's manual is provided as part of the package.

OVERVIEW

DRAM/EMPAL projects the interactions and distribution of employment and housing in a specified geographic area. DRAM/EMPAL combines two spatial interaction models: the Disaggregated Residential Allocation Model (DRAM) and the Employment Allocation Model (EMPAL) to quantify the interactions between the metropolitan patterns of employment and population location and the networks of transportation facilities that connect them. DRAM/EMPAL provides a tool that relates future estimates of the location and type of employment in an area to their prior distributions, regional growth or decline, and the region's transportation system.

DRAM/EMPAL formed the two major components of an integrated set of computer models known as the Integrated Transportation and Land Use Package (ITLUP). Output from DRAM/EMPAL (i.e.,employment and household location and land use, trips generated for home-to-work, home-to-shop, and work-to-shop) were used with the third component of ITLUP to perform standard travel demand modeling (including submodels to estimate trip distribution, modal choice, and traffic assignment). DRAM/EMPAL currently is the most widely used employment, population, and land use forecasting application; it has been used internationally in more than 4 dozen metropolitan areas.

DRAM/EMPAL has been incorporated into a new system called METROPILUS, which combines employment and residence location and land consumption into a single, comprehensive package operating within an ArcView GIS environment.

REQUIRED RESOURCES

Purchase Costs

$30,000 to $60,000. Purchase cost includes consultant services, maintenance, and training costs.

Equipment Needs

DRAM/EMPAL requires a MS Windows 95/98/NT operating system, a Pentium PC, color monitor, and printer. Spreadsheet, database, statistical, and ArcView geographic information system software are necessary for data management.

Staff Requirements and Expertise

Requires about one senior modeler with junior support.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

DRAM/EMPAL models the interrelationships among transportation, location, and land use in metropolitan areas. Land-use categories are further broken down into use by households by income group, streets, highways, employment type, and vacant or unusable land. Vacant lands are user defined and may contain various combinations of agricultural, and restricted land use types such as parklands, etc.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use		✔
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

Note: Any of the above questions may be answered "yes" when DRAM/EMPAL is linked to the right model, such as LANCON or METROPILUS. Without linking, most cannot be answered as such.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔	
Local Government Fiscal Conditions	✔	
Availability of Open Space	✔	
Environmental Quality	✔	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

Note: Any of the above categories with a "yes" may be addressed when DRAM/EMPAL is linked to the right model, such as LANCON or METROPILUS. Without linking, most cannot be answered as "yes."

Outputs Provided

Output	Format
EMPAL employment projections in each zone by economic sector	Standard formats such as Excel or dbf, and ArcView maps
DRAM projects the number of households in each zone by income level or any other user-defined level	Standard formats such as Excel or dbf, and ArcView maps
Submodel LANCON land consumption projections in each zone	Standard formats such as Excel or dbf, and ArcView maps
METROPILUS operates within GIS	ArcView maps

INFORMATION NEEDED TO RUN THE MODEL

This model requires the following user input:

- Regional level for EMPAL: Target year values of total employment by economic sector.

- Regional level for DRAM: Total population, total person trips by purpose, percent unemployment by sector, employees per household by household type, matrix of households by income per employee by sector, jobs per employee, and net regional rate of employee commuting.

- Analysis zone level for EMPAL (base year): Household by type, employment by sector, total land area, land area occupied by basic and commercial employment, zone-to-zone travel times and/or costs.

- Analysis zone level for DRAM (base year): Households by type, total population, total employed residents, group quarters population, land area use, land area occupied by basic and commercial employment, employment by sector, zone-to-zone travel times and/or costs.

Note: Data for DRAM/EMPAL are required both for the region, or overall modeling domain, and for each analysis zone. Input/output can be a number of different formats, including Excel or dbf.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Has been (and continues to be) used by numerous metropolitan areas and is a robust model.

- Has ability to introduce constraints or other influences, particularly to account for local knowledge.

- Input requirements use generally available data sources.

- Calibration of model is relatively easy.

Limitations

- DRAM/EMPAL modeling process is statistical, or aggregate theory based, rather than disaggregate or micro theory based; a reduced form of logit is used for location.

- Little or no scope to introduce planning policies other than land zoning, except by specific constraints or attractiveness functions.

- The absence of any mechanism for simulating the land market cleaning process underlying multi-year infrastructure change.

- The impact of zoning policies cannot be well represented in DRAM/EMPAL. Monetary and non-monetary incentives to guide land-use development cannot be represented in DRAM/EMPAL.

- Limited number of independent variables used to make projections may lead to underestimates of the full impact of some infrastructure improvements.

- The spatial resolution of the zones in DRAM/EMPAL is limited by a number of factors, the principal factor being availability of data.

- Sensitivity analyses are not possible.

- In order to achieve relative ease of use the model focuses on aggregate choice behavior rather than on individual choice behavior.

- The model requires training and experience to run correctly and efficiently. It is not an off-the-shelf product. It requires initial consultant involvement.

LEARNING MORE

Additional References

Putman, S.H. 1975. Urban land use transportation models: a state-of-the-art summary. *Transportation Research* 9:187-202.

Putman, S.H. 1983. *Integrated Urban Models*. Pion Limited, London. England.

Putman, S.H. 1984. Dynamic properties of static-recursive model systems of transportation and location. *Environment and Planning* 16A:1503-1519.

Putman, S.H. 1986. Future directions for urban systems models: some pointers from empirical investigations. Hutchinson, B. and Batty, M. (Eds.) *Urban Systems Modeling*. 91-108. Elsevier North-Holland, Amsterdam.

Putman, S.H. 1991. *Integrated Urban Models 2*. Pion Limited, London, England.

Rosenbaum, A.S. and Koenig, B.E. 1997. *Evaluation of Modeling Tools for Assessing Land Use Policies and Strategies.* Prepared for USEPA (EPA420-R-97-007).

Texas Transportation Institute. 1998. *Land Use Compendium*. Prepared for USEPA and USDOT.

Availability of Preview Copies of the Model

Not available.

Case Studies

- Northeast Illinois Planning Commission (Chicago MPO)
  Max Dieber
  Phone: (312) 454-0400

- Bart Lewis (model tester)
  Chief, Socioeconomic Analysis Division
  Atlanta Regional Commission
  Phone: (404) 364-2540

- The following Web site contains summaries of telephone interviews with MPOs who use DRAM/EMPAL:

  www.bts.gov/other/tmip/papers/landuse/compendium/dvrpc_toc.htm

Application Sites

- Southern California
- Atlanta Region
- Boston, MA
- Northeast Illinois
- North Central Texas
- Houston-Galveston, TX area
- Sacramento, CA
- Seattle, WA
- San Diego, CA
- Orange County, CA
- Kansas City
- Orlando/Kissimmee, FL
- Phoenix, AZ
- Portland-Vancouver, OR
- Colorado Springs, CO
- San Antonio, TX

Growth Simulation Model (GSM)

MODEL DEVELOPER(S): Joe Tassone

MAILING ADDRESS: Maryland Department of Planning
301 W. Preston Street, Room 1101
Baltimore, MD 21201-2385

CONTACT INFORMATION: *Phone:* (410) 767-4500
Fax:
E-mail: JTassone@mdp.state.md.us

WEB SITE: http://www.mdp.state.md.us

DOCUMENTATION: Developing Growth Management Options for Maryland's Tributary Strategies. Managing Maryland's Growth, Growth and Watershed Planning Series. Draft, March 1997.

OVERVIEW

The GSM was developed by the Maryland Office of Planning beginning in 1992 to project population growth and new development effects on land use/land cover nutrient pollution loads, and small streams under alternative land management strategies To develop these estimates, the GSM uses population, household, and employment projections to estimate demand for residential and commercial development. Demand is then distributed to developable land, based on capacity under existing or alternative zoning, development regulations, and resource conservation mechanisms; and on information about development patterns and trends. Land use change to accommodate projected growth is then estimated as a function of management tools.

REQUIRED RESOURCES

Purchase Costs

The GSM is public domain, but has not yet been adapted as an application that can be distributed to other users. Contact model developer for details.

Equipment Needs

The GSM is currently set up to run on a UNIX-based workstation or Windows NT. This could be modified to meet the needs of the user. Computer size and speed are a function of the database scale of resolution and the geographic extent of the study area. As it is currently being used, GSM requires a 500 MHz PC, 128 MB RAM, and 133 MHz bus speed. ArcInfo and a relational database (i.e., Paradox) software are also necessary to run GSM.

Staff Requirements and Expertise

It is necessary that staff running GSM are comfortable with GIS and relational database software. GSM has not been packaged for less skilled users. The target users of the model are land use planners and managers, and others interested in land and water resource conservation. Calibration and use of model requires experience in land use management and modeling and programming in relational database applications (e.g., Paradox, Oracle).

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The GSM can address many different user-defined land-use types. Under current implementation, the Maryland Office of Planning is using three categories of residential density, four types of non-residential developed land, four types of natural vegetation cover, and four categories of agricultural land. These land uses can be modified by the user. The following basic categories can be accommodated; additional information is provided in Appendix B.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔[1]	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔[2]	
Subdivision Regulations	✔	
Environmental Regulations	✔	

[1] Currently under development.

[2] No fiscal policies are pre-set in the model. However, if the user can provide specifications on the impact of the revenue source, then the policy can be incorporated.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔[1]	
Local Government Fiscal Conditions		✔[2]
Availability of Open Space	✔	
Environmental Quality	✔	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔
Land use	✔	
Stream buffers	✔	
Nutrient Pollution Loads	✔	

[1] Currently under development.

[2] Was under development, but has been put on hold due to lack of resources.

Outputs Provided

GSM generates land use and land use change information in a dataset that can then be tied to the original land use GIS dataset. Using the information in the GIS form, a varied set of statistics and graphics can then be generated by the user.

Output	Format
Land use projections	ArcInfo, Maps
Data Summaries	Relational Database files (e.g., Paradox) Spreadsheets Reports Graphs

INFORMATION NEEDED TO RUN THE MODEL

There is a great deal of flexibility regarding the data needed to run GSM. At a minimum, land use/land cover data and geo-referenced management areas are necessary to operate the model. An example of some of the data that have been incorporated into model applications are:

Input	Format
Land use	ArcInfo
Soils	ArcInfo
Watershed and county boundaries	ArcInfo
Streams	ArcInfo
Buffer zones	ArcInfo
Environmentally sensitive areas	ArcInfo
Zoning, growth, and land preservation boundaries	ArcInfo
Sewer service boundaries	ArcInfo
Population, household, and employment demographics	Database
Preserved land	ArcInfo

Additional information is also required about the effects of management alternatives. For example, typical lot yields in an R-1 zoning district are 3 D.U. / acre, and there are not forest conservation requirements for subdivisions. This information can be derived from empirical data or values can be assumed based on potential ranges.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Simulates land use change as a function of population, employment, land use management techniques, and market preferences.
- Can be customized to work a various levels of scale and detail.
- Can be used to extrapolate land use change for a much larger geographic area than that to which it was applied.

Limitations

- GSM has to be customized for each application by a skilled programmer, depending on the scale, resolution, and data used to represent generalized needs.

- Cannot currently map land use change in vector format as output. The user must currently use geo-referenced spheres or buffer polygons, statistics, and graphs to look at the change.

LEARNING MORE

Additional References

Chesapeake Bay Program. 1998. *Integrating Build-Out Analysis and Water Quality Modeling to Predict the Environmental Impacts of Alternative Development Scenarios.* CBP/TRS 178-97.

Tassone, J. 1998. *Smart Growth Options for Maryland's Tributary Strategies.* Maryland Office of Planning. Baltimore, MD.

Maryland office of Planning. 2000. *Methods used to Estimate 1997-2020 Land Use Change.* Baltimore, MD.

Population, Socioeconomic, and Land Use Task Force of the Scientific and Technical Advisory Committee, Chesapeake Bay Program. 1999. *Population Growth Land Use Change and Impacts to Land and Water Resources.*

Availability of Preview Copies of the Model

No preview copy is available. Contact model developer for additional information.

Case Studies

None

Application Sites

GSM has been utilized to estimate growth patterns across the state of Maryland in over 350 watersheds at a variety of spatial scales ranging from 3rd order streams, to major tributaries of the Chesapeake Bay, to the entire Chesapeake Bay Watershed (see *Population Growth, Land Use Change, and Impacts to Land and Water Resources*).

INDEX®

MODEL DEVELOPER(S): Criterion Planners/Engineers, Inc.

MAILING ADDRESS: 725 NW Flanders Street, Suite 303
Portland, OR 97209-3539

CONTACT INFORMATION: *Phone:* 503-224-8606
Fax: 503-224-8702
E-mail: eliot@crit.com

WEB SITE: www.crit.com

DOCUMENTATION: Available on the web site. Also, custom user guides are prepared for each community-specific version.

OVERVIEW

INDEX® was developed in 1994 to measure the characteristics and performance of land-use plans and urban designs with "indicators" derived from community goals and policies (e.g., measures the degree of transit orientation in a proposed residential subdivision).

REQUIRED RESOURCES

Purchase Costs

Negotiated fee dependant upon scope of community customization; fees range from $15,000 to $75,000.

Equipment Needs

INDEX® requires a 200 MHz or higher PC with 64 MB of RAM, 150 MB of free hard drive space, Microsoft Windows 95 or NT operating system, GIS software, color monitor with a minimum resolution of 800 x 600, and a color printer.

Staff Requirements and Expertise

Installation, calibration, and use of the model requires experience in ArcView GIS as well as land-use modeling expertise.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The number of land-use categories addressed by INDEX® is determined by the number of land-use categories in each community's unique land-use planning system. Therefore, the actual land-use categories are defined by the community and can be as detailed or general as needed. Typically, as few as 6 and as many as 30 categories are used.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure		✔
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Environmental Quality	✔	
School Quality		✔
Crime		✔
Other Quality of Life Conditions		✔

Outputs Provided

Outputs are determined by community customization. Selected results are mapped in ArcView shapefiles and some are stored in an Access database.

Example Outputs

- jobs/housing ratio
- residential density
- employment density
- land-use mix
- proximity to community amenities
- residential water consumption
- criteria air pollutant emissions
- street connectivity
- transit orientation
- parking supply
- imperviousness
- pedestrian route directness
- park and open space availability
- greenhouse gas emissions

INFORMATION NEEDED TO RUN THE MODEL

The number and type of inputs required are determined by each community during customization that includes topical scoping. Example inputs include:

Input	Format
Parcels	ArcView shapefile
Street centerlines	ArcView shapefile
Land-uses	ArcView shapefile
Dwelling units by type	ArcView shapefile
Employment by type	ArcView shapefile
Transit routes and stops	ArcView shapefile
Sidewalks	ArcView shapefile
Bicycle routes	ArcView shapefile
Off-street parking areas	ArcView shapefile
Building footprints	ArcView shapefile
Significant environmental features	ArcView shapefile

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Each copy is customized for a community's unique set of conditions and priorities.

- Integrates the explanatory power of GIS mapping with a comprehensive set of urban impact measurements.

- Provides communities with a consistent, efficient tool for evaluating incremental development proposals and monitoring the implementation of long-range land-use plans.

Limitations

- Requires detailed GIS data and user expertise.

- Must be in tandem with local four-step travel demand models in order to provide comprehensive land-use/transportation impact estimates.

- The land-use plan or urban design being evaluated must be created exogenously.

LEARNING MORE

Additional References

Refer to www.crit.com.

Availability of Preview Copies of the Model

Contact the model developer.

Case Studies

Local government operational use of the model does not typically produce narrative case studies, but instead generates indicator scores for a given plan or design. Federal use of the model has been documented in the following U.S. EPA Urban and Economic Development Division reports: *Transportation and Environmental Effects of Infill Versus Greenfield Development*, 1998; and *Transportation and Environmental Analysis of the Atlantic Steel Development Proposal*, Atlanta, GA, April 1999.

Application Sites

- Atlanta, GA (multiple locations)
- Beaverton, OR
- Coquitlam, BC
- Ft. Lewis, WA
- Kamloops, BC
- Montgomery County, MD (multiple locations)
- Orlando, FL
- Queens, NY
- San Diego, CA (multiple locations)
- Sacramento, CA
- West Palm Beach, FL

IRPUD

MODEL DEVELOPER(S): Michael Wegener

MAILING ADDRESS: Institute of Spatial Planning
University of Dortmund
D-44221 Dortmund
Germany

CONTACT INFORMATION:
Phone: +49 231 755 2291/2401
Fax: +49 231 755 4788
E-mail: mw@irpud.rp.uni-dortmund.de

WEB SITE: http://irpud.raumplanung.uni-dortmund.de/irpud/index_e.htm

DOCUMENTATION: See the web site listed above.

OVERVIEW

The IRPUD model projects the location decisions of industry, residential developers and households, the travel patterns that result from location decisions, construction activity and land-use development, and the impacts of public policies in the fields of industrial development, housing, public facilities, and transportation within an urban area over a specified amount of time.

The IRPUD model consists of six integrated submodels that address the following factors: transportation; changes to population, employment, residential buildings and non-residential buildings due to biological, technological or long-term socioeconomic trends; public programs; private construction; regional labor market; and regional housing market. Together, the six submodels form one comprehensive stand-alone model system.

REQUIRED RESOURCES

Purchase Costs

The IRPUD model is a research model developed through academic research projects funded by the German National Research Council. It is not available for purchase off-the-shelf as a self-contained software package. It is presently being used in a research project funded by the European Commission. In future projects, the IRPUD model will be included as a component of overall consulting services by the model developer, with the price of the overall consulting services being set on a project-by-project basis depending on several factors, including the needs of the client, the size of the study area, and the amount and condition of the data available for incorporation into the system.

Equipment Needs

The IRPUD model requires a 300 MHz or higher PC with 128 MB or more RAM, 4 GB or more hard drive space, color monitor (1024x768), color printer, Windows NT operating system, programming language compilers (e.g., FORTRAN, C, C++), and statistical analysis software (e.g., SAS, SPSS). In addition, a geographical information system (e.g., ArcInfo) is used to prepare the data needed to run the model. The model has its own result representation and analysis tools.

Staff Requirements and Expertise

The consulting services of the model developer are required to use the IRPUD model. The use and calibration of the model by the user requires land use modeling expertise.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands		✔
Water	✔	
Preservation		✔
Park Land		✔

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔	
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	

Community Characteristic	Yes?	No?
Environmental Quality	✔[1]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

[1]The IRPUD can forecast CO_2 emissions as a function of forecasting transportation-related indicators. Environmental submodels that calculate traffic noise and air pollution indicators are under development.

Outputs Provided

The IRPUD model generates graphical and tabular outputs. Graphical outputs are in the form of trajectories–curves representing the development of a particular model variable or output indicator over time–or maps. The table below lists examples of indicators that a user can select for output. Tabular output is in the form of ASCII printer output files. Graphical output is either on-screen or in WordPerfect WPG format for later post-processing and printing. In addition, custom-written programs are used to extract model results from the model data base for mapping.

Example Indicator Outputs Generated by the IRPUD Model:

- Percent foreign population
- Trips by trip purpose (work, shopping, education, other)
- Percent population 0–5, 6–14, 15–29, 30–59, 60+ years
- Trips by mode
- Households
- Mean travel time
- Total employment
- Mean travel cost
- Non-service, service, retail employment
- Car-km per capita per day
- Unemployment rate
- CO_2 emissions by car per capita per day
- Job-labor ratio
- CO_2 emissions by transport per capita per day
- Total dwellings
- Transport expenses per household per month
- Percent single-family dwellings
- Public transport expenses per household per month
- Housing floor space per capita
- Car ownership (cars per 1,000 population)
- Mean housing rent per square mile

INFORMATION NEEDED TO RUN THE MODEL

The user of the IRPUD model must provide four groups of data as inputs: model parameters, regional data, zonal data and network data. The table below presents the types of inputs that fall into each of these groups. All user input is in the form of ASCII files.

<table>
<tr>
<td>Model Parameters

These inputs influence the model equations contained in the IRPUD model.
Demographic parameters
Household parameters
Housing parameters
Technical parameters
Monetary parameters
Preference parameters</td>
<td>Regional Data

The IRPUD model requires information on the total urban region to project intraregional changes.
Employment
Immigration
Outmigration</td>
</tr>
<tr>
<td>Zonal Data

This information describes activities in the urban region undergoing analysis during the base year simulated by the IRPUD model. Each zone in the urban region must have the following information:
Population
Labor force/unemployment
Households
Dwellings
Households/housing
Employment/workplaces
Public facilities
Land use
Rents/prices</td>
<td>Network Data

The IRPUD model considers transport networks with modes car, public transportation and walk/bicycle. The model codes the following network information link by link using a multimodal coding scheme:
Link type
From-node
To-node
Link length
Link travel time (public transportation)
Base speed (road)
For each public transportation line, the IRPUD model codes the following information:
List of nodes
Peak-hour headway</td>
</tr>
</table>

MODEL STRENGTHS AND LIMITATIONS

Strengths

- The IRPUD model studies the impacts of policies from the fields of industrial development, housing, public facilities, and transportation. The model addresses global policies (i.e., those that affect urban development in the whole region) and local policies (i.e., regulatory or direct zone-specific investment projects).

- The IRPUD model differs from other operational urban models due to its high temporal resolution and its full integration of land-use transport interaction in each simulation period. This makes it a truly dynamic model (compared with other approaches, such as cross-sectional equilibrium approaches).

- The IRPUD model introduces assumptions about human spatial behavior drawn from time-space geography based on time and cost budgets and satisfying behavior into urban modeling. This makes the model uniquely suitable to model elastic trip generation behavior (responsible for much of the growth in mobility in metropolitan regions).

Limitations

- Limitations of the present version of the IRPUD model include its coarse spatial resolution and its lack of a submodel of urban freight transportation. The model developer is addressing both limitations in the ongoing revision of the model through the PROPOLIS project.

LEARNING MORE

Additional References

Wegener, M. 1998. *The IRPUD Model: Overview*. Dortmund: Institute of Spatial Planning. http://irpud.raumplanung.uni-dortmund.de/irpud/pro/mod/mod_e.htm.

Wegener, M. 1983. *Description of the Dortmund Region Model*. Working Paper 8. Dortmund: Institute of Spatial Planning.

Availability of Preview Copies of the Model

Contact the model developer.

Case Studies

Wegener, M. 1996. Reduction of CO2 emissions of transport by reorganisation of urban activities. In: Hayashi, Y., Roy, J. (eds.): Land Use. *Transport and the Environment*. Dordrecht: Kluwer Academic Publishers, 103-124.

Wegener, M., Mackett, R.L., Simmonds, D.C. 1991. One city, three models: comparison of land-use/transport simulation models for Dortmund. *Transport Reviews* 11, 107-29.

Wegener, M. 1998. Sustainable Urban Spatial Structures. Do We Need to Rebuild Our Cities? Dortmund: Institute of Spatial Planning. http://irpud.raumplanung.uni-dortmund.de/irpud/pro/co2/co2_e.htm.

Application Sites

The metropolitan region of Dortmund, Germany

Land Transformation Model (LTM)

(Other names: LTM-ANN (Artificial Neural Network); LTM-MCE (Multi-Criteria Evaluation; and LTM-LR (Logistic Regression).)

MODEL DEVELOPER(S): Dr. Bryan C. Pijanowski

MAILING ADDRESS: Michigan State University
231 Natural Science Building
East Lansing, MI 48824-1115

CONTACT INFORMATION:
Phone: (517) 432-0039
Fax: (517) 432-1054
E-mail: pijanows@msu.edu

WEB SITE: http://www.ltm.msu.edu

DOCUMENTATION: http://www.ltm.msu.edu/document
http://www.ncgia.ucsb.edu/conf/landuse97/papers/pijanowski_bryan/paper.html

OVERVIEW

Development of the Land Transformation Model (LTM) began in 1995 and is ongoing. The model uses landscape ecology principles, patterns of interactions to simulate land use change process, to forecast land use change. Though the model can be used in any definable region, precedence is given to watersheds as the spatial extent in LTM applications. Conceptually, the LTM contains six interacting modules: 1) policy framework; 2) driving variables; 3) land transformation; 4) intensity of use; 5) processes and distributions; and 6) assessment endpoints. The pilot model was developed for Michigan's Saginaw Bay Watershed and contains two of the six LTM modules; driving variables and land transformation. The pilot model integrates a variety of land use change driving variables, such as population growth, agricultural sustainability, transportation, and farmland preservation policies for the watershed.

REQUIRED RESOURCES

Purchase Costs

Contact the model developer. It is likely that there will be no associated costs to obtain the model and its associated routines.

Equipment Needs

LTM requires a 300 MHz or higher PC or Sun Sparc with a minimum of 256 MB RAM, Windows NT or Sun Solaris operating system, a color monitor with a minimum resolution of 1024 x 768 and a color printer. Spreadsheet (Excel), database (MS Access), statistical (S-Plus and SAS), programming language compiler ('C'), GIS (ArcView or ArcInfo), and Stuttgart Neural Network Simulator (SNNS) software are necessary for data management.

Staff Requirements and Expertise

Calibration and use of the model requires expertise in land-use modeling and "C" language programming as well as SNNS neural network batch files.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The LTM can address up to eight different land-use types.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial		✔
Mixed-Use		✔
Industrial		✔
Other		✔

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation		✔
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning		✔
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions		✔
Availability of Open Space		✔
Environmental Quality	✔	
School Quality		✔

Community Characteristic	Yes?	No?
Crime		✔
Other Quality-of-Life Conditions		✔

Outputs Provided

Output of the LTM includes a time series of projected land uses in the watershed at user specified time steps.

Output	Format
Land use projection maps	GIS (ArcInfo GRID)
Data Summaries	Excel

INFORMATION NEEDED TO RUN THE MODEL

To operate the model, a community must have a GIS data base that contains basic land use information. At a minimum, the following input data are needed:

Input	Format
Previous land use	ArcInfo GRID
Roads, highways, streets	ArcInfo Lines
Surface water (rivers, lakes, etc.)	ArcInfo lines or polygons
Elevation	ArcInfo GRID
Public lands	ArcInfo GRID
Population	ArcInfo GRID
Per capita use requirements	ArcInfo GRID

MODEL STRENGTHS AND LIMITATIONS

Strengths

- GIS outputs provide stakeholders and resource managers with easy to understand results.
- Allows users to explore various types of inputs that are parameterized using a GIS.
- Coupled to a neural network software package that learns how historical changes in use are driven by various social, political and environmental factors.

Limitations

- The “drivers” are not dynamic; projective ability is around 35% for 100m x 100m cell size.

- Takes several large C programs to couple the GIS and neural network simulation software.

- Environmental process models that are being used require large amounts of memory (around 2 GB of RAM for a 5- to 7-county area.

- The model requires training and experience to run. It is not a commercial off-the-shelf product. It was developed to be used by a researcher working with resource managers.

LEARNING MORE

Additional References

Several papers were in press at the time of publication of this report. Refer to web site for additional information.

Availability of Preview Copies of the Model

Contact the model developer.

Case Studies

Several projects utilizing the LTM are underway, refer to web site for more information.

Application Sites

Saginaw Bay, Michigan watershed

Land-Use Change Analysis System (LUCAS)

MODEL DEVELOPER(S): Michael W. Berry, Richard O. Flamm, Brett C. Hazen, Rhonda M. MacIntyre and Karen S. Minser.

MAILING ADDRESS: Department of Computer Sciences
114 Ayres Hall
University of Tennessee
Knoxville, TN 37996-1301

CONTACT INFORMATION: *Phone:* (865) 974-3838
Fax: (865) 974-4404
E-mail: berry@cs.utk.edu

WEB SITE: http://www.cs.utk.edu/~lucas

DOCUMENTATION: http://www.cs.utk.edu/~lucas/publications/pblications.html

OVERVIEW

LUCAS was developed in 1994 to examine the impact of human activities on land use and the subsequent impacts on environmental and natural resource sustainability. LUCAS stores, displays and analyzes map layers derived from remotely-sensed images, census and ownership maps, topographical maps, and outputs from econometric models using the Geographic Resources Analysis Support System (GRASS), a public-domain GIS. Simulations using LUCAS generate new maps of land cover representing the amount of land-cover change. Issues such as biodiversity conservation, conservation goals, long-term landscape integrity, changes in real estate values, species abundance, and land-ownership characteristics can be addressed by LUCAS.

REQUIRED RESOURCES

Purchase Costs

The model is public domain and is distributed upon request.

Equipment Needs

LUCAS requires a UNIX-based workstation (e.g., Sun SPARC station), Microsoft Windows with the OSF/Motif library toolkit (version1.21), a color monitor and a color printer. GIS (GRASS) and spreadsheet software is necessary to analyze the results.

Staff Requirements and Expertise

Calibration and use of the model requires expertise in land-use modeling and “C^{++}” language programming.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

Land-use is modeled as a multi-variate function of land cover change. This is a spatially-explicit modeling approach. LUCAS can address many different land-use types.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use		✔
Industrial		✔
Other		✔

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Environmental Quality	✔	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

Outputs Provided

Output of the LUCAS includes a time series of projected land uses in the watershed at user specified time steps. For each land cover type, the following output information is provided.

Output	Format
Area	Statistical (SAS) and graphical
Amount of edge	Statistical (SAS) and graphical
Edge/area ratio	Statistical (SAS) and graphical
Mean patch size	Statistical (SAS) and graphical
Number of patches	Statistical (SAS) and graphical
Cumulative frequency distribution of patches by size	Statistical (SAS) and graphical
Proportion of land cover	Statistical (SAS) and graphical
Amount of total edge	Statistical (SAS) and graphical
Standard deviation of patch size	Statistical (SAS) and graphical
Size of largest patch	Statistical (SAS) and graphical
Mean patch shapes	Statistical (SAS) and graphical

INFORMATION NEEDED TO RUN THE MODEL

To operate the model, a community must have the following GIS information. The GIS used by LUCAS is GRASS, but most commercial GIS software can readily convert their files to the GRASS format.

Input	Format
Transportation networks (access and transportation costs)	GRASS grid
Slope and elevation (indicators of land-use potential)	GRASS grid
Ownership (land holder characteristics)	GRASS grid
Land cover (vegetation)	GRASS grid
Population density	GRASS grid

MODEL STRENGTHS AND LIMITATIONS

Strengths

- LUCAS provides a graphical user interface that is intuitive and easily understood by users with a wide range of technical abilities and experience.

- The system provides a flexible and interactive computing environment for landscape management studies.

Limitations

- As a non-commercial GIS package, many bugs still exist in the GRASS software. Also, some of the features of GRASS are not well-documented.

- The model requires training and experience to calibrate. It is not a commercial off-the-shelf product and was developed to be used by a researcher working with resource managers.

LEARNING MORE

Additional References

M.W. Berry, B.C. Hazen, R.L. MacIntyre, and R.O. Flamm. 1996. Lucas: A System for Modeling Land-Use Change. *IEEE Computational Science & Engineering*, Vol. 3, No. 1, 1996, pp. 24-35.

M. W. Berry, R.O. Flamm, B.C. Hazen, and R.L. MacIntyre. 1994. *The Land-Use Change Analysis System (LUCAS) for Evaluating Landscape Management Decisions*. Technical Report CS-94-238, University of Tennessee, Knoxville, TN, December 1994.

R.L. MacIntyre, B.C. Hazen, and M.W. Berry. 1994. *The Design of the Land-Use Change Analysis System (LUCAS): Part I - Graphical User Interface.* Technical Report CS-94-266, University of Tennessee, Knoxville, TN.

Also, please refer to web site.

Availability of Preview Copies of the Model

Refer to web site and contact the model developer for additional information as needed.

Case Studies

LUCAS was developed and implemented for the Little Tennessee River Basin and for the Hoh and Dungeness watersheds in the Olympic Peninsula.

Application Sites

- Little Tennessee River Basin, Tennessee
- Olympic Peninsula, Washington

Markov Model of Residential Vacancy Transfer

MODEL DEVELOPER(S): Philip Emmi and Lena Magnusson

MAILING ADDRESS: Professor Philip Emmi
Geography Department
University of Utah
260 S. Central Campus Drive, Rm 270
Salt Lake City, UT 84112-9155

CONTACT INFORMATION: *Phone:* (801) 581-5562
Fax: (801) 581-8219
E-mail: pcemmi@geog.utah.edu

WEB SITE: www.geog.utah.edu/faculty/emmi.html

DOCUMENTATION: Philip C. Emmi and Lena Magnusson. 1995. Opportunity and mobility in urban housing markets. *Progress in Planning*, 43(1): 1 - 88.

OVERVIEW

The Markov Model of Residential Vacancy Transfer explores changes in demand for various types of residential housing (e.g., high-density apartments or condos, single-family detached dwellings, etc.) within a community as various subpopulations, such as single adults, young families, and empty nesters transition through the community from one housing environment to another. The model could be applied to help plan new residential zoning and development based on existing demographics and population pressures, or to identify where certain residential sectors or areas might decline without coordinated efforts to accommodate demographic changes. The model would be particularly useful for small towns and cities on the metropolitan fringe seeking to establish, and redeveloping inner cities trying to re-establish, a sustainable housing landscape throughout existing and future residents' lifetimes.

REQUIRED RESOURCES

The model is a mathematical formula based on linear algebra and ordinary differential equations–it is not a discrete software package. Pre-processing of inputs and developing the formula can be implemented with a variety of statistical analysis software (e.g., SAS, SPLUS, SPSS).

Purchase Costs

None.

Equipment Needs

Any type of computer can be used; there are no specific hardware or software requirements.

Staff Requirements and Expertise
Extensive.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial		✔
Mixed-Use		✔
Industrial		✔
Other		✔

Nonurban Land-Use Categories	Yes?	No?
Agricultural		✔
Forest		✔
Wetlands		✔
Water		✔
Preservation		✔
Park Land		✔

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure		✔
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions	✔	
Availability of Open Space		✔
Environmental Quality		✔
School Quality		✔
Crime		✔
Other Quality of Life Conditions		✔

Outputs Provided

Output	Format
A simulation of intra-urban household moves between residential sectors across a census or projection period	Explicit numerical output
Probabilities of residential mobility by household type as a function of the sectoral distribution of vacancy initiations, the pattern of housing sector interaction and the sectoral distribution of households	Numerical matrix
A measure of housing sector interaction in terms of the probability of a vacancy introduced into sector "I" being associated with a residential move in sector "J"	Format type not available

INFORMATION NEEDED TO RUN THE MODEL

Input	Format
Residential addresses, both past and present, classified into "internally homogeneous" housing sectors (e.g., single-family residences, retiree apartment complexes, single-parent public housing, etc.) within a specified area	Any electronic format that can be read by the user's statistical analysis software
Households and their past and present addresses, the community, or area, as derived either from sequential census records or a survey of recent household creations, conclusions, and moves	Any electronic format that can be read by the user's statistical analysis software

Note: Emmi (1994) relaxes the requirement for "internally homogeneous" sectors to ease exposition and facilitate inter-urban comparisons.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- The model simulates impacts of new vacancies on urban residential relocations and the accommodation of new entrants (immigrants, newly formed households) into the housing market.

- The model also simulates impacts of newly created vacancies on the residential mobility for various urban sub-groups (e.g., single professionals, young families, wealthy empty nesters).

- The model achieves a high level of projective accuracy.

Limitations

- The model depends on a stable, semi-closed system of residential moves between census years.
- The model does not explicitly simulate land-use changes.
- The model examines only discrete sectors of the residential housing market.
- By focusing on vacancy transfers, the model speaks only indirectly to behaviorally-based adjustments in housing accommodations.

LEARNING MORE

Additional References

Emmi, P.C. 1990. A model of monopolistic competition among sectors of a metropolitan housing market. *Netherland Journal of Housing and Environmental Research* 5: 87-103.

Emmi, P.C. and Magnusson, L. 1988. Residential vacancy chain model of an urban: Exercises in impact and needs assessment. *Scandinavian Housing and Planning Research* 5: 129-145.

Emmi, P.C. and Magnusson, L. 1993. Intrasectoral homogeneity and the accuracy of multisectoral models. *Ann. Reg. Sci.* 27:343-363.

Emmi, P.C. and Magnusson, L. 1994. The projective accuracy of residential chain vacancy chain models. *Urban Studies* 31(7): 1117-1131.

Emmi, P.C. and Magnusson, L. 1995(b). Further evidence on the accuracy of residential vacancy chain models. *Urban Studies* 32(8): 1361-1367.

Availability of Preview Copies of the Model

Not applicable because the model has not been implemented as its own software. Authors' papers, however, provide examples and procedures for implementing this model.

Case Studies

Case-study information is summarized in several academic papers listed above.

Application Sites

Application sites are identified in the academic papers listed above. The sites include:

- 3 Swedish cities
- 42 U.S. metropolitan areas

MEPLAN

MODEL DEVELOPER(S): Developed by Marcial Echenique/Ian Williams

MAILING ADDRESS: Marcial Echenique and Partners (ME&P)
49-51 High Street
Trumpington, Cambridge CB2 2HZ
England

CONTACT INFORMATION: *Phone:* +44(0) 1223 840704
Fax: +44(0) 1223 840384
E-mail: admin@meap.co.uk

WEB SITE: www.meap.co.uk

DOCUMENTATION: User, technical, and programming manuals are available from the developer.

OVERVIEW

MEPLAN was developed to help communities analyze the inter-related effects of land use and transportation policies. Specifically, MEPLAN can: 1) determine the effects of transport on the choices of location by residents, employers, developers, and others; 2) determine how land use and economic activity create the demand for transport; and 3) project and evaluate the many impacts that planning decisions will have on land use and transport. MEPLAN is an integrated software package of modules that enables users to look at supply and demand in both land and transport, and compare the effects of one policy with those of another policy. These comparisons may include physical changes, economic benefits, and social and environmental indicators. MEPLAN also incorporates a forecast capability to assess: 1) what is likely to happen through time given certain assumptions about economic growth, 2) how the most likely 'reference' scenario would be altered as a result of specific policy measures in a future year, 3) how prices will be affected (e.g., house prices, cost of living, production costs, etc.)

Three main modules are provided in the model: 1) Land use/economic module (LUS), 2) Transport module (TAS), and 3) Economic evaluation module (EVAL). LUS combines a spatial model with a variable relationship input-output model to project where factors will locate and what the pattern of trades will be between zones. TAS examines modal split, route assignment, and capacity restraint. An interface program (FRED) between TAS and LUS deals with the two-way interactions between these two modalities. FRED enables MEPLAN to estimate the number and distribution of trips or flows directly from the results of the land-use model. FRED also is able to calculate the reverse interaction–how transport changes affect the pattern of land uses. EVAL combines the results of LUS, TAS, and FRED and compares them to alternative plans or to a base-case scenario.

REQUIRED RESOURCES

Purchase Costs

MEPLAN costs about $25,000 to purchase and about $640 per day to train someone to operate and use the model. Annual estimated maintenance costs are approximately 10% of the purchase price.

Equipment Needs

MEPLAN requires a 200 MHz or higher PC with 64 MB of RAM, Microsoft Windows NT operating system, and an associated graphics system such as MEPLUS/MapInfo.

Staff Requirements and Expertise

Installation, calibration and use of the model requires training in MEPLAN as well as experience in land-use and transportation modeling. A typical small team to operate MEPLAN will consist of a planner, a transport engineer, and an economist. Specialists in computing should not be needed. Training in the use of MEPLAN is provided as a consulting service by the developer.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The land-use categories addressed by MEPLAN are user defined and therefore could include any land-use category.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔	
Local Government Fiscal Conditions	✔	
Availability of Open Space	✔	
Environmental Quality	✔	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

Outputs Provided

Specific outputs are dependent on how the user has set up the model within the analytical framework it provides and what the model is being used to test. MEPLAN could potentially generate the following outputs:

- Employment by sector
- Population by income group
- Households by car ownership group
- Land area by activity
- Floor space by activity
- Price by floorspace/land type

INFORMATION NEEDED TO RUN THE MODEL

MEPLAN was designed to be flexible to meet the needs of the user; therefore, it does not have rigid input requirements. Because MEPLAN provides a framework that can be adapted to suit a variety of user needs, the inputs required to operate the model are user defined and can be altered for each run of the model. The MEPLAN framework incorporates a land/use economic model and a transport model, so information (inputs) on land use, floor space, supply and demand for land and buildings, prices for space, pattern of prices, availability of public transport, ownership of cars, road and rail infrastructure, trip types, and related information would be useful.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- MEPLAN comes close to modeling interrelated variables in cities.

- The model allows analysis of different kinds of policies.

- The highly synthetic nature of the model allows most of the description of even the base situation to be estimated within the model, reducing the reliance on observed data.

- It is possible to implement the MEPLAN with very little data other than that for the base year. MEPLAN includes floor space zoning restrictions in the spatial choice formulation as well as development costs, which allows for the impact of zoning policies to be represented.

- In MEPLAN, the development of floor space is projected, in part, on the basis of development costs. Therefore, policies that offer monetary incentives to developers to build in targeted zones or at specified densities could be represented in terms of decreased development costs.

Limitations

- MEPLAN is quite data-intensive. Calibration process can be difficult and time consuming if base year observed data is lacking or inconsistent.

- Validation of base year results may be problematic if suitable observed data is lacking.

- There is no way to integrate data for years subsequent to the base year. (The model could be recalibrated to a later year if suitable data are available, or a partial update could be done with a subset of more up-to-date data).

LEARNING MORE

Additional References

Research into Practice: the Work of the Martin Centre in Urban & Regional Modelling. Special issue of *Environment & Planning B: Planning & Design*, Vol. 21(5), pages 513-650, 1994.

Availability of Preview Copies of the Model

Not available.

Case Studies

A wide range of case study project summaries are available from the model developer.

Application Sites

- London, England
- South East of England
- Cambridge, UK
- Santiago, Chile
- Sao Paulo, Brazil
- Bilbao, Spain
- Tokyo, Japan
- Helsinki, Finland
- Caracas, Venezuela
- Sacramento, USA
- Naples, Italy
- Bolzano, Italy
- Madrid, Spain
- San Sebastian, Spain
- Basque Region, Spain
- Colombia (national model)
- Chile (national model)
- Sweden (national model)
- Sao Paulo state, Brazil
- Central Region of Chile

METROSIM

MODEL DEVELOPER(S):	Alex Anas & Associates
MAILING ADDRESS:	151 Rollingwood Street Williamsville, NY 14221-1855
CONTACT INFORMATION:	*Phone:* 716-688-5816 *Fax:* 716-688-5816 *E-mail:* aanas@adelphia.net *URL:* http://www.acsu.buffalo.edu/~alexanas
WEB SITE:	http://www.bts.gov/tmip/papers/landuse/compendium/dvrpc_ch1.htm#1.4.3 http://www.nsf.gov/cgi-bin/showaward?award=9816816
DOCUMENTATION:	Please e-mail Alex Anas to receive an electronic copy of documentation

OVERVIEW

METROSIM is an operational large scale computer simulation model that uses an economic approach to forecast the interdependent effects of transportation and land use systems and of land use and transport policies at the metropolitan level. METROSIM is used to evaluate transportation projects and travel related changes, land use controls, employment growth scenarios, income growth and other polices or forecast changes.

METROSIM can be used to obtain quantitative forecasts of travel flows, employment changes, congestion levels, new construction of residential and commercial buildings, land use changes, etc. The user can specify land use constraints and zoning regulations in the model. The user can also obtain benefit-cost ratios for projects or policy interventions simulated by METROSIM.

METROSIM can produce a one-shot long run equilibrium forecast for transportation and land use in a metropolitan area, or METROSIM can operate in annual increments and produce yearly changes to transportation and land use from the existing situation until convergence to a steady state is achieved.

REQUIRED RESOURCES

Purchase Costs

To purchase: $20,000–$30,000

To run the software: $2,500 for three initial runs or negotiable. Full reports are included.

To maintain the model software: User support for $5,000–$10,000/year

Train to use the software: $10,000 one time

Equipment Needs

METROSIM requires a 300 MHz or higher computer (PC, MacIntosh, or Sun Sparc) with 128 MB of RAM, color monitor, FORTRAN or C programming language compilers, Excel or Access for data management, SAS or SPSS statistical analysis software, and ArcInfo or MapInfo. It can be adapted to any operating system, but UNIX is preferred.

Staff Requirements and Expertise

No technical land-use experience is required–only general computer experience is necessary. Participation of the model developer is necessary for its use.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The categories and number of land uses addressed by the model are user defined with no limit. It all depends on the level of available data, but at least two residential, two non-residential, and three vacant uses are recommended.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic)	**Yes?**	**No?**
Travel Demand	✔	
Local Government Fiscal Conditions	✔	
Availability of Open Space	✔	
Environmental Quality	✔[1]	
School Quality	✔	
Crime	✔	
Other Quality-of-Life Conditions	✔	

[1] For water quality only, not for air quality.

Outputs Provided

Output	Format
Basic industry distribution by zone and by type of basic industry.	As desired.
Non-basic industry distribution by zone and by type of non-basic industry.	As desired.
Residential real estate distribution by type and zone.	As desired.
Non-residential real estate distribution by type and by zone.	As desired.
Vacant land distribution by type and by zone.	As desired.
Households	As desired.
Travel (commuting and non-work)	As desired.
Traffic assignment on the network	As desired.
Rents and market prices for each type of real estate by zone	As desired.
Vacancy rates for each type of real estate	As desired.
Graphical outputs available–this is a special feature which can be provided upon request at a modest fee.	As desired.

INFORMATION NEEDED TO RUN THE MODEL

This model requires the following user input:

- CTPP elements 1, 2, and 3, and Bureau of the Census STF1A and STF3A files.
- Transportation network’s link-node description in MapInfo, ArcInfo, or other format.
- Land use by type of land use desired in the model.

- If available, regional input/output model

- If available, land and property values by zone and land use type. Please note that file formats are not important because files can be easily converted from one format to another.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- It is a model firmly rooted in economics and recognizes how market forces operate in shaping and changing land use

- It is very rapid on the computer and does not rely on approximate solutions.

- It deals explicitly with land use policy and land use change

Limitations

- Currently does not have a GIS interface but that can be easily developed at a small fee.

LEARNING MORE

Additional References

See http://www.acsu.buffalo.edu/~alexanas.

Availability of Preview Copies of the Model

Potential users must contact the developer.

Case Studies

- Alex Anas (model tester)
  151 Rollingwood Street
  Williamsville, NY 14221-1115
  Phone: 716-688-5816
  Fax: 716-688-5816
  E-mail: aanas@adelphia.net
  URL: http://www.acsu.buffalo.edu/~alexanas

- Kazem Oryani (used model in operational context)
  URS Consultants, Inc.
  1 Penn Plaza, Suite 610
  New York, NY 10119-0698
  Phone: 212-736-4444
  E-mail: Kazem_Oryani@urscorp.com

- Contact Alex Anas for information and reports on the following specific applications:
  - New York Region to test effects of region-wide transport scenarios
  - Harlem Line Corridor
  - Staten Island MIS alternatives

Application Sites

- Chicago, IL
- Houston, TX
- Harlem Line Corridor, New York City, NY
- New York City, NY Region
- Pittsburgh, PA
- Staten Island, NY
- San Diego, CA

SAM-IM
(Sub-Area Allocation Model-Improved Method)

MODEL DEVELOPER(S):	Planning Technologies, LLC
MAILING ADDRESS:	1816 Lomas Boulevard, NW, Suite A Albuquerque, NM 87104-1206
CONTACT INFORMATION:	*Phone:* (505) 243-8088 *Fax:* (505) 243-5655 *E-mail:* plantech@all4gis.com
WEB SITE:	http://www.all4gis.com
DOCUMENTATION:	Planning Technologies, LLC. July 1999. SAM-IM User's Guide (developed for exclusive use by the Maricopa Association of Governments).

OVERVIEW

The Sub-Area Allocation Model-Improved Method (SAM-IM) is a land use allocation and forecasting model developed for the Maricopa (Arizona) Association of Governments to support official adopted forecasts of land use in the region for use by the transportation and air quality programs in Maricopa County. Another version of this model includes the Land Use Analysis Model (LAM) that was also developed by Planning Technologies, LLC for the Middle Rio Grande Council of Governments (Albuquerque, New Mexico). The Albuquerque application was used to analyze the implications associated with various approaches to regional growth control. Planning Technologies, LLC develops and implements each version of this model based on the needs and unique features of the users, usually planners and other decision-makers affiliated with governmental organizations such as associations/councils of governments.

SAM-IM uses geographic information systems (GIS) to access data, including acreage, population, and employment, to investigate existing land use relationships and construct future land use scenarios. The basic concept behind SAM-IM was inspired by earlier work conducted at the University of California-Berkeley by Dr. John Landis. SAM-IM is essentially a modeling platform for generating forecasts and allocations of land use according to methods similar to those which have appeared in the literature under Dr. Landis' name.

SAM-IM projects future land use patterns based on a simulation of growth and development in a region. Urbanization is simulated by evaluating lands available to absorb growth based on various site suitability characteristics, such as potential net profit as measured by various surrogates such as highway access, proximity to infrastructure, consistency with zoning and general plans, local development policies, etc. Land found by the model to be most likely to be developed, based on its native site suitability characteristics, is "built."

The user defines the specific allocation methodology in SAM-IM, so the application suite can support a variety of specific theories of urban growth that fall into this general approach framework. SAM-IM offers considerable adaptability and flexibility: it can be altered to fit a locality's own definitions of land uses and can be programmed to reflect whatever principles or factors are thought (by the user) to most influence growth and development. Virtually any factor that can be represented geographically (as an ArcView shape file) can be taken into consideration.

The land use (and other) layers in SAM-IM are all represented by ArcView shape files. The allocation mechanism itself, however, treats geographies as high-resolution cellular (raster) features, using ArcView's Spatial Analyst extension. SAM-IM provides automated routines to convert between vector (polygon) and raster (also called grid, pixels or cells) representations of land use and other themes (e.g., flood plains, redevelopment districts, retirement communities, etc).

SAM-IM provides planners with a number of capabilities, including:

- Analyzing Land Use Plans: Analysis of land use plans, whether it be a database of existing land use, or a proposed plan, with respect to measures of sustainability. SAM-IM provides a number of measures of relationships between different types of land use, such as measures of job-housing balance, for either a region or for individual communities in a region.

- Creating and Editing Land Use Plans: The application is equipped with editors to support the development of new urban forms that can reflect different philosophies about growth and development. The new urban forms may promote infill development in the established urban area; they may promote corridor development around transportation facilities; or they may reflect current development trends. Whatever the urban form concept, SAM-IM provides the planner with a toolbox of editing and drawing tools to create the database to reflect the growth management strategy.

- Creating Site Evaluations: The application is equipped with a toolbox that make the creation of site evaluation themes (i.e., themes that describe the characteristics of land and its suitability to be developed) easy. Special tools in the toolbox let planners create themes that, for example, convert conventional shape file themes (e.g., flood plains) to grid, measure feature proximity (e.g., to highways or infrastructure), provide neighborhood measures (e.g., market within 3 miles of a site), etc.

- Projecting Future Land Use Patterns: Forecasting of growth, or more accurately, to disaggregate or allocate a spatial growth forecast for a region. SAM-IM does so by giving the planner a way to represent the value of land and the probability that it will be developed. SAM-IM simulates the development of a region in a way that is consistent with overall regional projections, consistent with existing land use, and consistent with the land use plan.

- Supporting Other Urban Model Systems: The SAM-IM platform includes a "geographic calculator" that lets users easily create and format data sets used by other modeling systems to complete an urban growth analysis, including transportation models such as those built for EMME/2.

The result of a SAM-IM simulation is a land use map which depicts land use throughout the region for some future year.

REQUIRED RESOURCES

Purchase Costs

SAM-IM software currently is not available for purchase off-the-shelf as a self-contained software package. It is included as a component of overall consulting services provided by the model developer. The price of overall consulting services is set on a project-by-project basis depending on several factors, including the needs of the client, the size of the study area, and the amount and condition of the data available for incorporation into the system. Typically, the total cost ranges from $30,000–100,000.

Equipment Needs

SAM-IM requires a 400 MHz or higher IBM (or compatible) computer with 128 MB of RAM and 2 GB free hard drive space, an MS Windows NT or MS Windows 95 operating system, color monitor and printer, and ArcView 3.2 (with the Special Analyst Extention). Visual BASIC compiler not required but is helpful. Statistical software necessary for calibration only.

Staff Requirements and Expertise

The consulting services of the model developer and in-house staff that understand ArcView are required to use SAM-IM, and similar models created by the model developer.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

SAM-IM is capable of including any kind of land use data. The data included in the model depends on what land uses the user would like to include, and what data is available. Therefore, the user defines the actual land use categories (up tp 40), which can be as detailed or as general as needed.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other (e.g., business park, institutional)	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔	
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Environmental Quality		✔
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

Outputs Provided

Output	Format
Distribution of future land uses	GIS maps

INFORMATION NEEDED TO RUN THE MODEL

Before SAM-IM can perform an allocation, the user must provide certain inputs into the model. There are also optional inputs that the user can incorporate into the model, but are not necessary for the model to run.

Input	Format	Required/Optional
Dwelling unit density for each land use type (to generate a regional forecast)	Text file	Required
Employment density for each land use type (to generate a regional forecast)	One-digit Standard Industrial Classification (SIC) Codes	Required
Existing land use layer	GIS coverage	Required
Proposed land use layer	GIS coverage	Required
Proposed project information	GIS coverage	Optional
Other areas of concern (e.g., protected habitat, stream buffers)	GIS coverage	Optional

MODEL STRENGTHS AND LIMITATIONS

Strengths

- SAM-IM contains an editor feature that allows users to edit land use files while maintaining planar polygon topology that ArcView shape files conventionally do not support. Planners can add, delete, copy, paste, and split land use polygons and can recode them with new uses and densities with the help of on-screen forms. Planners can also create an on-screen encyclopedia of known project types and densities with which to draw on when coding land use themes.

- SAM-IM contains a toolbox of functions to make site evaluation themes that control the forecasting process easy to construct. The functions significantly extend ArcView's own capabilities for cellular representation of geography (known as "grid") offered in the Spatial Analyst. They let users build cellular land use grids, grids from any other conventional polygon theme on any attribute, compute new grids, compute new grids through look-up tables, measure proximities, feature buffers, and neighborhood sums etc. All of these features are of particular interest when creating a consolidated set of factors that influence development probability and potential.

- SAM-IM lets users create and forecast new land use "scenarios." Scenarios typically represent alternative land use plans, growth policies, and target years. So time-series of long-range forecasts over extended periods of time, by five year intervals, can be supported.

- The allocation process in SAM-IM will not violate land use policies for a region, for example the projection of future land uses will not violate the uses and densities adopted as part of zoning or general plan maps. This feature was especially highly regarded in Maricopa County, whereby previous models generated forecasts that were in conflict with adopted planning policy.

- SAM-IM contains a "geographic calculator" feature by which planners can generate new datasets used by other urban models, such as transportation models. The calculator summarizes land use according to any zone-based geography of interest, such as traffic analysis zones, municipal boundaries, school district boundaries, etc. In addition, it can compute new socioeconomic variables from equations (e.g., population) from dwelling unit descriptions and assumptions about dwelling unit vacancy rates and persons-per-households all expressed geographically), automatically recognizing and manipulating the geographic unit for which the terms of the equation are expressed in. Virtually any output file format can be created, including dBASE files, delimited ASCII files, and fixed format ASCII files for use in other programs.

- SAM-IM provides numerous measures of relationships between different types of land use, such as measures of job-housing balance, for either a region or for individual communities in a region.

- SAM-IM can also operate on a "microscopic level." It can provide a user with a forecast for an area smaller than an acre.

- Communities can use SAM-IM to evaluate alternative land use scenarios against local performance indicators developed by the community.

Limitations

- SAM-IM is targeted for major agencies responsible for forecasting land use, with mature GIS support capabilities, systems, and databases and a significant degree of GIS expertise on-staff.

- SAM-IM can be too complicated for a community to use without assistance from the model developer. It has a steep initial learning curve, which can affect the technical expertise and resources needed to use this model.

- Although SAM-IM addresses a wide variety of land uses, its treatment of mixed uses and redevelopment is presently cumbersome. These areas have been targeted for improvement in the future.

LEARNING MORE

Additional References

Presentation at the ESRI International Users Conference, June, 2000; San Diego, CA.

Availability of Preview Copies of the Model

Contact the developer to arrange for an on-site presentation and demonstration.

Case Studies

Not specified.

Application Sites

- Maricopa County, AZ
- Albuquerque, NM metropolitan area

SLEUTH

MODEL DEVELOPER(S) Keith C. Clarke

MAILING ADDRESS: Geography Department
University of California, Santa Barbara
Ellison Hall 3620
Santa Barbara, CA 93106-4060

CONTACT INFORMATION: *Phone:* (850) 893-7961
Fax: (850) 893-3146
E-mail: kclarke@geog.ucsb.edu

WEB SITE: http://www.geog.ucsb.edu/projects/gig

DOCUMENTATION: http://www.ncgia.ucsb.edu/projects/gig/model_document.htm
All available documentation on SLEUTH can be found on the above web site.

OVERVIEW

The SLEUTH (Slope, Land use, Exclusion, Urban, Transportation, Hillshading) model, commonly known as the Clarke Cellular Automata Urban Growth Model or as the Clarke Urban Growth Model, is intended to simulate urban growth in order to aid in understanding how expanding urban areas consume their surrounding land, and the environmental impact this has on the local environment. SLEUTH derives its name from the six types of data inputs: slope, land use, urban, exclusion, transportation, and hillshading. This model simulates the transition from non-urban to urban land-use using a grid of cells (cellular automaton) each of whose land-use state is dependent upon local factors (e.g., roads, existing urban areas, topography), temporal factors, and random factors.

REQUIRED RESOURCES

Purchase Costs

None – may be downloaded for free at http://www.ncgia.ucsb.edu/projects/gig/download.htm

Equipment Needs

The SLEUTH model requires a PC, workstation, or mainframe with a UNIX operating system and gnu C compiler (gcc). X-Windows is required for graphical version.

Staff Requirements and Expertise

Installation and calibration of the model requires experience in UNIX operating system, text editor, and gnu C compiler (gcc), as well as land-use modeling expertise. Use of the model requires land-use expertise and familiarity with UNIX operating system, text editor, and gnu C compiler (gcc). Familiarity with X-Windows and X-libraries also important for graphical versions.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The SLEUTH model assumes two land use maps and a set of predefined land use categories with names assigned by the user (e.g., a numeric value, such as 6, in the land cover file to represent forest nonurban land uses). The model handles any combination of user-defined land-use categories, including those represented in the tables below.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions	✔[1]	
Availability of Open Space	✔	
Environmental Quality	✔[1]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

[1] Any fiscal or environmental impact which can be estimated as a function of urbanized area could be developed for the output of this model, but the model does not do so directly.

Outputs Provided

The model provides outputs as a set of GIF image files that can be merged into an animation or brought into a GIS as data layers. Resolution of output images depends on the resolution of the input data.

Output	Format
Snapshot of a particular year	GIF image file
Cumulative image that results from multiple runs and show a probability of urbanization for a given year (i.e., Monte Carlo image that results from Monte Carlo probability runs)	GIF image file
A set of best fit metric between modeled and real data for calibrating the model	–
Actual values of model output for control years averaged over the number of model simulations	–
The standard deviations of the average actual values	–
Ending coefficient values	–
The start and stop times for an entire model execution	–

INFORMATION NEEDED TO RUN THE MODEL

Input	Format
Slope: Derived from average from a DEM (Digital Elevation Model)	GIF
Excluded areas: Water bodies and other land where urbanization cannot occur.	GIF
Roads/transportation network	GIF
Seed	GIF
Background	GIF
ASCII "schedule" files control when images are read. These include: • Urban.dat. • Landuse.dat (deltatron) • Roads.dat • Landuse.classes (deltatron)	–

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Concurrently simulates four types of growth (spontaneous, diffusive, organic, and road-influenced)
- Provides both graphical and statistical outputs.
- Incorporates momentum of booms and busts using threshold multiplier with subsequent temporal decay.
- Allows for relatively simple alternative scenario projection.

Limitations

- The model does not explicitly deal with population, policies and economic impacts on land use change, except in terms of growth around roads.

LEARNING MORE

Additional References

Clarke, K.C., Hoppen, S. and Gaydos, L. 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay Area. *Environment and Planning B: Planning and Design*. vol. 24, pp. 247-261.

Clarke, K. C. and Gaydos, L. 1997. Long Term Urban Growth Projection Using A Cellular Automaton Model and GIS: Applications in San Francisco and Washington/Baltimore. *International Journal of GIS*, Special Issue of Population Modeling and Development, (Under Review).

Clarke, K.C., Hoppen, S., Gaydos, L. 1996. *Methods and Techniques for Rigorous Calibration of a Cellular Automaton Model of Urban Growth.* Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, January 21-25, 1996. Santa Barbara: National Center for Geographic Information and Analysis.

Kirtland D., DeCola L., Gaydos L., Acevedo W., Clarke K., Bell C. 1994. An analysis of human-induced land transformations in the San Francisco Bay/Sacramento area. *World Resource Review*. vol. 6(2); pp 206-217. (URL: http://edcdgs9.cr.usgs.gov/urban/pubs.html)

Kramer, J. 1996. *Integration of A GIS with a Local Scale Self-Modifying Urban Growth Model in Southeastern Orange County, New York*. M.A. Thesis. Hunter College-CUNY.

Availability of Preview Copies of the Model

The SLEUTH Model can be downloaded from
http://www.ncgia.ucsb.edu/projects/gig/download.htm

Case Studies

- Leonard Gaydos, Chief (tested model)
  Research, Technology and Applications
  USGS Western Mapping Center
  345 Middlefield Road, MS 531
  Menlo Park, CA 94025-3591
  Phone: 650-329-4330
  Fax: 650-329-4710
  Email: lgaydos@usgs.gov

Application Sites

- Baltimore-Washington, DC
- Chester County, PA
- Orange County, CA
- Santa Barbara, CA
- San Francisco, CA
- Sterling Forest, NY
- Utah Front Range, UT
- Chicago-Milwaukee
- Detroit, MI
- Greater New York Area
- Mid-Atlantic Interstate Area
- Middle Rio Grande Basin, NM
- Philadelphia-Wilmington, PA

Smart Growth INDEX ®

MODEL DEVELOPER(S): Criterion Planners/Engineers, Inc.
(with Fehr & Peers Associates, Inc.)

MAILING ADDRESS: 725 NW Flanders Street, Suite 303
Portland, OR 97209-3539

CONTACT INFORMATION: *Phone:* 503-224-8606
Fax: 503-224-8702
E-mail: eliot@crit.com

WEB SITE: www.crit.com

DOCUMENTATION: Available on the web site.

OVERVIEW

Smart Growth INDEX® was developed in 1998 to help communities evaluate alternative land-use and transportation scenarios, including regional growth management plans, land-use and transportation plans, and land development proposals. It is a customizable, GIS-based tool that evaluates the different scenarios by scoring their outcomes using a set of environmental indicators. Smart Growth INDEX® can operate in two basic modes: it can provide forecasts over time and parcel-based "snapshots" at a single point in time. An underlying assumption of the model is that population and employment growth are directly related to a locale's accessibility to transportation and infrastructure services. It contains an internal travel demand submodel that allows the user to estimate transportation outcomes from land-use changes without the use of a traditional four-step transportation model. Smart Growth INDEX® is a sketch-level planning tool intended to provide a preliminary analysis of alternative growth scenarios, land-use plans, and urban designs to aid a community in defining alternatives that warrant a closer look.

REQUIRED RESOURCES

Purchase Costs

Initial versions of Smart Growth INDEX® became available in mid-1999 at no cost through the U.S. EPA Urban and Economic Development Division. Enhanced versions currently are under development. For final pricing, contact developer.

Equipment Needs

Smart Growth INDEX® requires a 300 MHz or higher PC with 64 MB of RAM, 500 MB of free hard drive space, Microsoft Windows 95 or NT operating system, GIS software, color monitor with a minimum resolution of 1024 x 768, and a color printer.

Staff Requirements and Expertise

Installation, calibration, and use of the model requires experience in GIS as well as land-use and transportation-based modeling.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The number of land-use categories addressed by Smart Growth INDEX® is determined by the number of land-use categories in each community's unique land-use planning system. Therefore, the actual land-use categories are defined by the community and can be as detailed or general as needed. Typically, 6--30 categories are used.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔	
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Environmental Quality	✔	

Community Characteristic	Yes?	No?
School Quality		✔
Crime		✔
Other Quality of Life Conditions	✔	

Outputs Provided

The output files are dependent upon the type of analysis being performed (i.e., forecast or snapshot). For a forecast analysis, the performance indicators (output files) are scored for interval and the designated horizon years. For a snapshot analysis, a similar set of indicators are scored for a single point in time. All tabular results are provided in dbf file format. Selected results are mapped in ESRI shapefiles and some are stored in an Access database.

Forecast Analysis Outputs

- growth compactness
- residential population
- employment density
- land-use mix
- incentive area
- housing density
- housing transit proximity
- employment transit proximity
- jobs/housed workers balance
- vehicle miles and hours traveled
- vehicle hours of delay
- mode split
- auto travel cost
- air pollution
- climate change
- residential energy and water consumed

Snapshot Analysis Outputs

- population density
- land-use mix
- residential density
- diversity of housing type
- housing proximity to transit
- jobs/housed workers balance
- employment density
- employment proximity to transit
- street connectivity
- energy consumption
- criteria air pollutant emissions
- park space availability
- housing proximity to recreation
- open space
- pedestrian orientation
- pedestrian route directness
- vehicle miles traveled
- vehicle trips
- street network density
- auto travel costs
- residential water consumption
- greenhouse gas emissions

INFORMATION NEEDED TO RUN THE MODEL

To operate the model, a community must have a GIS database containing basic land use, transportation, housing, and employment information. At a minimum, the following inputs are required:

Input	Format
Existing housing by type	ESRI shapefile
Existing employment by job count and location	ESRI shapefile
Current and/or proposed land-use plan designations by class	ESRI shapefile
Street centerlines by functional class	ESRI shapefile
Transit lines by type	ESRI shapefile

If the model is operated in tandem with TRANSCUD or MINUTP, two common travel demand models, then a traffic analysis zone (ESRI shapefile) also is required.

Optional inputs include the following:

Input	Format
Features that constrain urbanization; e.g., agricultural soils, steep slopes	ESRI shapefile
Incentives areas for urbanization; e.g., transit corridors, brownfields	ESRI shapefile
Existing and planned infrastructure service areas and facilities	ESRI shapefile
Existing traffic counts by street segments	ESRI shapefile
Local jurisdiction boundaries	ESRI shapefile
Other subarea boundaries, such as traffic analysis zones or census tracts	ESRI shapefile

If the model is operated in tandem with TRANSCUD or MINUTP, then cross-classification matrix of persons per household and auto ownership by housing type can also serve as input.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Smart Growth INDEX® provides communities with a consistent, efficient tool for evaluating alternative growth scenarios, land-use plans, and urban designs.

- The model integrates the explanatory power of GIS mapping with a comprehensive set of urban impact measurements.

- The model can either be operated with an internal abbreviated four-step travel demand sub-model or be linked to the TRANSCAD or MINUTP travel demand models.

Limitations

- The model requires detailed GIS data and user expertise and land-use and transportation modeling expertise.

- The parameters and assumptions that control the spatial allocation of the growth forecast do not include the effects of land prices.

- The method used for spatially allocating the growth forecast is “hard coded” and cannot be readily modified by users.

LEARNING MORE

Additional References
Refer to www.crit.com.

Availability of Preview Copies of the Model
Contact the model developer.

Case Studies
Not available.

Application Sites
- Sacramento, CA
- Newark, DE
- Gainesville, FL
- Indianapolis, IN
- Covington, LA
- Boston, MA
- Baltimore, MD
- Carol County, MD
- Westminster, MD
- St Paul, MN
- Wildwood, MO
- Wilmington, NC
- Las Vegas, NV
- Charleston, SC
- Houston, TX
- San Antonio, TX
- Burlington, VT
- Milwaukee, WI

Smart Places

MODEL DEVELOPER(S): Electric Power Research Institute (EPRI)
Contact: Paul Radcliffe

MAILING ADDRESS: 3412 Hillview Avenue
Palo Alto, CA 94304-1344

CONTACT INFORMATION: *Phone:* (650) 855-2720
Fax: (650) 855-2619
E-mail: pradclif@epri.com

WEB SITE: http://www.epri.com or www.smartplaces.com

DOCUMENTATION: The user's manual and the developer's manual can be obtained from Paul Radcliffe (EPRI).

OVERVIEW

Smart Places, Version 4.0, is a geographic decision support system created to assist communities in the design and evaluation of land-use development alternatives with user-selected criteria. Smart Places provides an interactive computer tool that allow communities to explore and design alternative development plans, and evaluate environmental and economic impacts of a proposed design. The model allows users to define the parameters to be used for evaluation. Smart Places is intended to be customized for specific locations and design objectives and can be applied to small rural towns as well as large urban areas.

Smart Places is an extension of Environmental Systems Research Institute's (ESRI) ArcView geographic information systems software, and includes the following tools:

- Tools to explore data and related documentation allowing users to review data layers and retrieve documentation while constructing land-use design scenarios. Users can browse and select design backdrops such as land-use designations, economic characteristics, transportation networks, or aerial photographs.

- Tools for scenario design allowing users to construct geographic designs displaying familiar landmarks, aerial photographs, and proposed features. Users can assign land use categories with a table of attributes (e.g., total area of building, number of employees, and estimated energy consumption) for each category.

- Tools for scenario evaluation allowing users to define the scope of the scenario to be considered for evaluation. For example, users can evaluate the entire design or interactively select land-use categories, regions, or other boundaries within the design. Smart Places then uses development features (e.g., energy or water) with evaluation models to conduct a cause and effect analysis to determine the viability and impact of a design alternative.

- Tools for production of design scenarios and evaluation results allow the user to plot data, export graphics, and store data layers for scenario design and analysis reports. Results can be printed using distinctive graphical layouts including data layers, images, symbols, and explanatory text.

REQUIRED RESOURCES

Purchase Costs

Contact Paul Radcliffe (EPRI) for cost information.

Equipment Needs

Smart Places requires a 120 MHz or faster PC with a Pentium chip, Windows 95/98 or higher operating system, a minimum of 32 MB of RAM, 1 GB free hard disk space, a CD-ROM drive, and ERSI ArcView Geographic Information System software. A color monitor is recommended but not required.

Staff Requirements and Expertise

Use of the Smart Places model requires no land use experience and only general computer experience. Making significant changes in customizing the model, however, may prove difficult for an inexperienced user.

Smart Places has scaled menus that accommodate four expertise levels:

(1) New user – people using the program for the first time, or with minimal experience with the program.

(2) Experienced user – people with considerable experience in using the program.

(3) ArcView user – “experienced users” that also have considerable experience using ArcView.

(4) Manager – developers or other technical people with the capability to make changes in the program code.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

Because Smart Places is customized to accommodate the user’s own data, the number and type of land-use categories will vary from application to application. Smart Places users define their own land use categories as appropriate for their study area and there is no limit the number of land use categories. Smart Places can accommodate one or more land use categories (e.g., residential, commercial, etc.) as themes associated with a particular project.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔[1]	
Local Zoning	✔[1]	
City/County Master Plans	✔[1]	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔[1]	

[1] Smart Places can be customized to evaluate the impact of changes in land use patterns based on user-specified criteria.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔[1]	
Local Government Fiscal Conditions	✔[1]	
Availability of Open Space	✔[1]	
Environmental Quality	✔[1]	
School Quality	✔[1]	
Crime	✔[1]	
Other Quality-of-Life Conditions	✔[1]	

[1] Smart Places can be customized to evaluate these impacts based on user-specified criteria.

Outputs Provided

Output	Format
Evaluation results comparing scenario results with assigned goals and boundaries for each evaluation parameter	Report
ESRI “shape files”	Displayed as bit-mapped images and graphical displays of analysis results

INFORMATION NEEDED TO RUN THE MODEL

Inputs will depend on the goals and objectives of the user. Typically, the more detailed inputs the user can provide, the more in-depth analyses can be performed. Depending on the user’s objectives, likely data inputs include:

- Standard ArcView coverages with information on: 1) natural features; 2) infrastructure plans; 3) existing land use patterns; and 4) approved comprehensive plans or zoning ordinances (ArcView files and other data files). Data may include attributes related to features stored in a variety of file formats.

- User generated analysis models (models can be written in several programming languages, including Avenue, C++, and Visual Basic) used to evaluate alternative designs.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Easy to use: The Smart Places graphical user interface supports four distinct user levels, from new users to programmer/developer. Users can prepare and evaluate alternative land use scenarios using simple, narrative, pull-down menus.

- Customizable: Smart Places is intended to be customized by the user, allowing the system to model specific locations and design objectives.

- System integration: Smart Places provides the user the ability to link to models written in Avenue or other programming languages, including C++ and Visual Basic.

Limitations

- Not a self-contained system: Smart Places is an extension of ESRI’s ArcView GIS. Users must have ArcView to use Smart Places.

- Lack of sophisticated modeling: Smart Places provides an open system that allows users to evaluate the impacts of alternative development scenarios. The users must provide data inputs and evaluation models.

- Expertise: Some background in GIS is desirable for all user levels beyond "new users."

LEARNING MORE

Additional References

DOE Internet site for Center of Excellence for Sustainable Development. http://www.sustainable.doe.gov/

Electric Power Research Institute, enPhysic Denver Inc. November 1998. *Smart Places E Series User Manual, Version E4E.*

Public Technology Inc.. September 1997. *Denver Smart Places Sustainable Development Project* (Case study report)

Smart Places Strategic Decision Support Software. A paper presented at the EPA Brownfields Conference, 1998.

Availability of Preview Copies of the Model

Potential users must contact Paul Radcliffe, EPRI. A partnership is being formed with Public Technology, Inc. to bring the model to cities in the United States.

Case Studies

- Preston White (tested model)
  University of Virginia
  Charlottesville, VA 22906
  Phone: (804) 982-4561
  Fax: (804) 982-2678
  E-mail: kpw8h@virginia.edu

- Matthew Foster (used model in operational context)
  Pueblo of Sandia
  P.O. Box 6008
  Bernalillo, NM 87004
  Phone: (505) 867-3317

Application Sites

- Denver, CO
- 38 other sites have license agreements to use

TRANUS

MODEL DEVELOPER(S): Modelistica

MAILING ADDRESS: P.O. Box 47709
Caracas 1041A
Venezuela

CONTACT INFORMATION: *Phone:* +58(2)761-5432
Fax: +58(2)761-7354
E-mail: info@modelistica.com

WEB SITE: http://www.modelistica.com/tranus/

DOCUMENTATION: The most up to date documentation may be obtained by contacting the developer by e-mail at info@modelistica.com. The web page contains a large amount of material that complements the basic documentation.

OVERVIEW

The Tranus Integrated Land Use and Transport Planning System (TRANUS) model is intended to assist transportation and land use planners in simulating and evaluating transportation, economics and/or environmental policies at an urban, regional or national scale. The integrated land use-transport modeling makes possible an assessment of the implications of transport policies on the location and interaction of activities, and its effects on the land market. Compared to transport-only models, it provides projections to the future, based on the growth and location of activities instead of increasing trip matrixes by applying growth factors not directly related to changes in accessibility or functionality of the study area.

TRANUS reproduces the behavior of the different agents in the urban or regional area; the way they relate and interact, their consumption patterns, and the consequent use of the supply of land, floorspace, transport services and transport infrastructure. The model also allows for the definition of any number of ‘scenarios’ with corresponding policies and projects to simulate. A base case scenario is used to compare results and obtain the probable effects of applying particular policies and projects. The model calculates many indicators to evaluate these effects, from social, economic, to financial and energy points of view.

REQUIRED RESOURCES

Purchase Costs

Purchase the model software:	$7,500
Run the model software:	Included
Maintain the model software:	One-year guarantee included; one-year extensions may be acquired at 50% of cost which means the that user group receives a new versions with a software guarantee and technical support.
Train to use the model software:	A typical 2-week, full-time course is in the order of $8,000 plus expenses

A common scheme that has been adopted in the past is that the agency interested in applying the model provides the data and Modelistica performs the calibration of the model and even projections into the future based on alternative scenarios. If training is added, the agency can continue with the work on its own. This kind of turn-key operations may be arranged at very competitive rates.

Equipment Needs

TRANUS requires a PC with enough RAM to run a Windows 95/98/NT operating system (64 MB or higher advisable), and free hard drive space of 10 MB for programs plus 20 MB or more, depending on the size and complexity of the model implementation. A color monitor is required and a color printer is useful, as is a digitizer but only if a network has to be digitized. In terms of software, Windows-based spreadsheets word processors and presentation programs; statistical analysis software (e.g., SAS, SPSS); a geographic information system (e.g., ArcView, ArcInfo).; and a logit calibration program (e.g., Alogit or Hielow) are useful but not essential.

Staff Requirements and Expertise

Installation and calibration of the model requires experience with Office suites and GIS, as well as land-use modeling expertise. Use of the model requires land-use expertise and familiarity with Office suites and GIS.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

There are no fixed categories to TRANUS. Any number of land use categories may be defined, limited only by available information and the objectives of the project. The model is flexible to be set with the categories normally used in the planning offices or master plans of the study area. They are introduced into TRANUS with their familiar names and measured in any convenient units. The modeler also defines the functional relationships between the categories. Consequently, the potential user does not have to look anywhere for the definitions and descriptions, since he or she would have defined them. What the model does with the categories, relations and data is fully described in the documentation.

TRANUS is an Activity Location, Land-use, and Transport model. Not only land-use categories need to be defined, but also activities like population (by income groups or household size) employment (by type), education (employment and students) and any other relevant activity in the study area. Relationships like which activities consume which types of land may be specified. Restrictions on land consumption or on activities may be specified to reflect land use policies. Attracting variables may be added to represent environmental quality, historical values, social aspects, crime rates, or any other.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔	

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔	
Local Government Fiscal Conditions	✔	
Availability of Open Space	✔	
Environmental Quality	✔[1]	
School Quality	✔	
Crime	✔	
Other Quality-of-Life Conditions	✔	

[1] Addresses changes in criteria pollutants, changes in greenhouse gases, energy consumption, and emissions from buildings. In the case of environmental indicators, TRANUS provides the inputs required for other models, such as CUFM, Burden, etc.

Outputs Provided

TRANUS produces many more outputs than the sample included below. Many matrices are provided: trips by category, mode, or operator. Matrices of costs, distances, time, and disutilities. Matrices of trips that use selected links, selected assignment results by cordon, link type, V/C relation and so on.

All transport outputs are graphically represented in vector format by the graphic user interface of TRANUS. Any Windows program can process the graphic outputs of TRANUS. Graphics may be imported to word processing or presentation programs (Word, Excel, PowerPoint, etc.) through cut-and-paste.

Output	Format
All paths between each O-D pair for each transport mode and combination of modes through transfers.	Vector images produced by the Graphic User Interface, which can be customized in color, scale, labels and many other features and pasted to any Windows application: word processors, spreadsheets, and other graphic programs for further customizing and printing. Optional ASCII file produced with the sequence of modes and links in each path.
General assignment results for each link: total volume in demand units (passengers or Tons), vehicles, equivalent vehicles, V/C ratio and level of service.	Numeric and graphic outputs available with the graphic TRANUS User Shell system in the windows environment, and tab delimited files generated for spreadsheets and database programs.
Detailed assignment results for each link: volume by each mode and route, speed and waiting times in the link under congestion conditions, demand/capacity ratio for transit vehicles.	Numeric and graphic outputs available with the graphic TRANUS User Shell system in the windows environment, and tab delimited files generated for spreadsheets and database programs.
Many indicators about the performance of the transport system to feed evaluation processes, organized by the three agents: users, operators and administrators. For users, TRANUS reports global demand by mode and transport category, total and average travels time, distance, cost and disutility by transport category. For operators, TRANUS reports the number of passengers (or Tons) passenger-Km (or Ton-Km) their income (from tariffs), their operating costs and revenue in the simulation period. For administrators of the transport infrastructure, TRANUS reports maintaining costs and incomes for tolls, road pricing or any other charges.	Tab delimited files generated for spreadsheets and database programs.

Output	Format
A database file, with a database format, containing all results of the transport model. The planner can process the file at will with any database program to extract specific information that is not standard output of TRANUS.	Tab delimited files for spreadsheets and database programs.
Routes profile, with demand-supply information for each route in each link: number of passengers boarding the route in the link, waiting time for boarding passengers, demand/ capacity of transit vehicles in each link, available seats and so on.	Tab delimited files for spreadsheets and database programs.
Activity location and land use consumption outputs.	Tab delimited files for spreadsheets and database programs.

INFORMATION NEEDED TO RUN THE MODEL

This model requires the following user input:

- Network nodes, links and routes (comma delimited text files generated by any GIS program can be imported to TRANUS). Alternatively, small networks can be interactively created in the graphic window of TRANUS with the mouse.

- Transport variables (introduced in the database with the Windows-like menus and commands provided by the TRANUS User Shell).

- Activity location and land use data by zone (copied from any worksheet or GIS and pasted to the TRANUS database).

- Activity location and land use variables (introduced in the database with the Windows-like menus and commands provided by the TRANUS User Shell or copy-and-paste from spreadsheet).

MODEL STRENGTHS AND LIMITATIONS

Strengths

- TRANUS is one of the very few integrated land use and transport models commercially available, backed by a sound history of practical applications in many countries.

- TRANUS is extremely user-friendly, with a powerful graphical Windows-based interface. The interface is supported by a dynamic object-oriented database, with GIS interface capabilities. From the beginning, the model was developed for use on personal computers, and it pioneered the area.

- TRANUS' 'site-license' allows installing the software in any computer of the institution, which makes it easy for work groups and to use the model for teaching.

- TRANUS has extensive email support that is provided with the license.

- The model can be applied to a large variety of case studies, ranging from very simple urban or regional models to highly sophisticated national or regional input-output models.

- TRANUS is backed by a continuous research and development process. Every year a new main version of TRANUS is released, with many upgrades to the main version produced monthly, based on the experience of applications and suggestions or requests of users, including Modelistica. An ambitious 'Millennium Edition' is soon to be released.

Limitations

- TRANUS is not a traffic model yet. The model was designed for planning, for strategic decisions about main policies: railroads, metro systems, new highways, master plans, input-output relations and so on. After many years of development and applications, Modelistica expanded the model to cope with detailed urban applications, including a sophisticated representation of transit systems (routes, frequencies, transfers, and queuing theory to calculate waiting times) with capacity restriction and dynamic assignment. However TRANUS does not cover all aspects of traffic models, such as calculating signal times or intersection movements.

- The graphic interface of TRANUS provides full graphic information of transport data and simulation results. However, for the graphical display of activities and land use data and results, a GIS software such as ArcView, TransCAD or MapInfo to map the results of the model is required.

- TRANUS includes a sophisticated model of the supply-side of the estate market including redevelopment. However, this new feature requires further testing. An agreement between Modelistica and the University of California is underway t o advance this area.

LEARNING MORE

Additional References

De la Barra. 1989. *Integrated Land Use and Transport Modeling*. Cambridge University Press. (Available in most bookstores and Internet facilities such as www.amazon.com, Barnes & Noble, Heffers, etc.)

Modelistica. *Mathematical and Algorithmic Structure of TRANUS* (see www.modelistica.com/tranus/tranus2.htm)

Modelistica. 1993. *Multidimensional Path Search and Assignment*. Paper presented at the 21st PTRC Summer Annual Conference, Manchester, England.

Modelistica. 1994. *Improved Logit Formulations for Integrated Land Use, Transport, and Environmental Models*. Paper presented at the Royal Institute of Technology, Stockholm, Sweden.

Modelistica. 1996. Dual Graph Representation of Transport Networks. *Transportation Research*, Vol. 30 No. 3, pp. 209-216, Exeter, England.

Availability of Preview Copies of the Model

Potential users must contact the model developer.

Case Studies

- Professor Robert Johnston (tested model)
  University of California Davis
  1 Shields Avenue
  Davis, CA 95616-5200
  Phone: (916) 752-6580
  Fax: (916) 752-3350
  Email: rajohnston@ucdavis.edu

- Patrick Costinett (used model in an operational context)
  Parsons Brinckerhoff
  8011 NE 121st Street
  Kirkland, WA 98034-5833
  Phone: (206) 557-8588
  Fax: (425) 820-9358
  Email: pcostinett@worldnet.att.net

Application Sites (this is only a sample)

- Year: 1999
  Project: Detailed Transport Demand Study for the Bogota Metro Systems, Columbia
  Consultant: Cal & Mayor Consultants, Bogota, Columbia
  Client: Urban development Institute of Santa Fe, Bogota, Columbia

- Year: 1998–99
  Project: Land Use and Transportation Model for the city of Valencia, Spain.
  Consultant: TEMA Consultants, Spain
  Client: Local government of Valencia, Spain (Ayuntamiento)

- Year: 1998–99
  Project: Land Use and Transportation Model for the Baltimore Metropolitan Areas, USA
  Consultant: Modelistica
  Client: Baltimore Metropolitan Council, USA

- Year: 1997–98
  Project: An Input-Output and Transport Model for the State of Oregon
  Consultant: Parsons Brinckerhoff, USA
  Client: Oregon Department of Transportation

UGrow

MODEL DEVELOPER(S): Wilson W. Orr

MAILING ADDRESS: Prescott College
220 Grove Avenue
Prescott, AZ 86301-2990

CONTACT INFORMATION: *Phone:* (520) 717-6070
Fax: (520) 717-6073
E-mail: worr@prescott.edu

WEB SITE: http://www.prescott.edu

DOCUMENTATION: UGrow an Urban Growth Model, Prescott College, Sustainability and Global Change Program, Prescott, AZ 8630-2990, (520) 717-6070. The model is documented within the model diagrams and equations itself.

OVERVIEW

UGrow is a system dynamics suite of models for urban policy design and testing. Numeric (system dynamics), spatial (GIS - maps) and 3-Dimensional (fly through visualization) are tools which are integrated to serve a community's needs. UGrow is part of an overall process of working with community leaders to identify drivers of change in the region, adapting the core UGrow model to address those drivers, and then testing a variety of future scenarios based on changes in local development policy, input conditions, or external variables.

UGrow is PC-based running over 300 equations, which define the basic interdisciplinary relationships among the economic, social, and environmental sectors of a community. The model runs from 1950 to 2100 with pauses at years 1990 and 2030 for policy adjustments. It is designed to test proposed policies and can be stopped at any year to produce the community status as a scenario responding to the proposed policy(s). There are presently ten policy option categories which encourage/discourage efficiencies in, for instance: housing density, energy consumption, transportation, land use/land cover, and business activity. Each of these may be adjusted for "intensity," representing the strength with which the policy is implemented. From the inputs and various policy options, the model produces a variety of future scenarios and projects variables groups into sectors such as: Quality of Life, Economics and Business, Housing, Population, Land Use, Transportation, Climate Change Impacts, and Energy. The numerical output is then used to generate GIS-format maps of the "future communities."

REQUIRED RESOURCES

Purchase Costs

Model software is free. However, for the model(s) to be useful to a community, the developer must adapt the model(s) to the community's particular data. This costs anywhere from $30,000 for a quick visual (spacial model) to $200,000 to include a more sophisticated numeric model and multiple facilitated public meetings.

Equipment Needs

UGrow requires an IBM PC with Windows 95, ArcInfo, ArcView, and Powersim modeling software. Minimal speed, RAM, and hard drive space is necessary.

Staff Requirements and Expertise

The installation and calibration of the UGrow model requires land use modeling expertise, as well as system dynamics, GIS, and facilitation experience. The model is to be used by trained system dynamics and GIS modelers. At the end of the process, a "flight simulator" can be created that would require no modeling experience and only general computer experience.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The UGrow model, at present, addresses only four land-use categories; however, the model is quite adaptable based on the community's modeling needs.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is not capable of addressing the effects on land-use patterns from changes in any of the following community actions. The general core of the model focuses on land use changes.

Community Action	Yes?	No?
Transportation Infrastructure		✔
Local Zoning		✔
City/County Master Plans		✔
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	**Yes?**	**No?**
Travel Demand	✔	
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Environmental Quality	✔[1]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

[1] Only includes effects of changes on greenhouse gases.

Outputs Provided

Output	**Format**
Data tables within the modeling software	Powersim
Graphs within the modeling software	Powersim

INFORMATION NEEDED TO RUN THE MODEL

The UGrow model requires the following user input:

- Spatial
- Social
- Housing
- Economic
- Vehicle Use
- Environment
- Public

MODEL STRENGTHS AND LIMITATIONS

Strengths

- A whole system approach
- Highly adaptable to specific concerns
- Model emphasizes building understanding over generating answers

Limitations

- Requires year-long adaptation with consulting team
- Extensive model advisory committee input needed
- Not a projection tool

LEARNING MORE

Additional References

Not provided.

Availability of Preview Copies of the Model

Potential users must contact model developer.

Case Studies

- Wilson W. Orr (tested model and used model in operational context)
  Prescott College
  220 Grove Avenue
  Prescott, AZ 86301-2290
  Phone: (520) 717-6070
  Fax: (520) 717-6073
  E-mail: worr@prescott.edu

Application Sites

- Eastern Pima County, AZ (Tucson area)
- Gallatin County, MT
- Santa Barbara, CA
- Yavapai County, AZ
- Oahu and Maui, HI
- Green Bay, WI
- Cayuga County, NY (on the waiting list)

UPLAN

MODEL DEVELOPER(S): Developed by Robert Johnston at University of California, Davis; built by David Shabazian

MAILING ADDRESS: UPLAN; Robert Johnston
Dept. of Environmental Science and Policy
University of California Davis
1 Shields Avenue
Davis, CA 95616-5200

CONTACT INFORMATION:
Phone: 530-582-0700
Fax: 530-582-0707
E-mail: rajohnston@ucdavis.edu

WEB SITE: Will be on the Information Center for the Environment's web site at http:// ice.ucdavis.edu in the near future.

DOCUMENTATION: Contact the model developer.

OVERVIEW

The UPLAN Urban Growth Model ("UPLAN") provides a land use evaluation and change analysis based on general land-use plans, population and employment projections, characteristics of housing, and other user-defined conditions. It is an integrated package of user-specified attractions that enable users to: 1) conduct a land suitability analysis, and 2) project future land use demand. UPLAN helps communities create alternative visions for their area's future by mapping alternative development patterns determined by local land development policies. Some of the policies and decisions UPLAN addresses include establishing various criteria to "weight" the suitability of different locations for a particular land use, incorporating various land use planning and zoning considerations and other allocation scenarios, and defining various growth scenarios. The model can also be used to determine various environmental and social constraints to growth by modifying the criteria and the associated weights.

The UPLAN model allows the user to develop specific parameters in the form of grids in which to model future land uses. The model allows the user to generate attraction grids, exclusion grids, general plan grids, and existing urban grids. Attractive grids are locations for future development (i.e., near to freeway ramps); exclusion grids, list areas where development should not occur (i.e. parks, waterways etc.); general plan grid is a composite grid of the general plan land use maps from the users region; and existing urban grid provides the current land use conditions. Each grid applies user-defined decision criteria (e.g., identifying and weighting grid factors), to derive study-area conditions. These decision criteria are applied to land use information stored in geographic information system (GIS) data files to create maps and reports showing where future development may occur.

REQUIRED RESOURCES

Purchase Costs

The UPLAN software is available for free from the model developer.

Equipment Needs

UPLAN requires a 300 MHz or higher IBM PC (or other computer type that can run Windows 95/98 or NT 4.0), 32 MB of RAM, several hundred MBs (a few GBs even better) of hard drive space, and a color monitor (recommend at least 21" monitor). Color printer and plotter recommended, but not required. Software requirements include PC ArcView (need PC ArcInfo if wish to prepare data layers for local applications) and Excel or SAS for data exchange with other models.

Staff Requirements and Expertise

Use of the model requires land-use expertise and basic knowledge of ArcView. Also, users will need to be able to program in Avenue to adapt the model to their data sets and policy needs. A three-county application in New Mexico by inexperienced users required about 3 person months of ArcView user, plus about 2 weeks of consulting by an Avenue programmer.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

UPLAN can accommodate up to six different types of land uses, as is, (industry; high- and low-density commercial; and high-, medium-, and low-density residential) and can be modified to accommodate any number of categories. Because UPLAN can be customized to accommodate the user’s own data, the number and type of land-use subcategories will vary from application to application.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action)	**Yes?**	**No?**
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔[1]	

[1] Can be done only for developer impact fees, property taxes, municipal sewer and water fees, subsidies, and parking fees.

UPLAN is policy-oriented, scenario-based land use change projective tool. It shows the likely impacts of different user-supplied assumptions concerning land suitability, land use demands. Market mechanisms, such as subsidies and taxes can be coded in as subareas with positive or negative values.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	**Yes?**	**No?**
Travel Demand	✔[1]	
Local Government Fiscal Conditions	✔	
Availability of Open Space	✔	
Environmental Quality	✔[2]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

[1] Not directly, but the land uses can be taken into the zone files of any travel model.

[2] In terms of air quality, changes in criteria pollutants and greenhouse gases can not be estimated directly but can be done by feeding the land uses into any travel model. In terms of water quality, a model is under development for nutrient loading or sedimentation in surface waters and other nonpoint source water pollution.

Outputs Provided

Output	Format
Grid Maps	ArcView layouts (GIS)
Analysis Report	Report
Assumptions Report	Report
Image Files	ArcView layouts (GIS)

INFORMATION NEEDED TO RUN THE MODEL

The inputs listed below are desired, but not required for UPLAN since the model can be run with default values. The more detailed specific inputs the user provides, the more accurate the analysis. The desired inputs include:

- Demographic and land use factors, population projections, persons per households, assumed housing densities per land use, average parcel size for each density class, employment by type, assumed employment density. (Hand entered by system user).

- Regional General Plans, and incorporated city areas provided by users Local Planning Organization. (Hand entered by system user).

- All roadway and intersection data obtained from U.S. Geological Survey (USGS) digital line graphs. Data must be entered for each development scenario.

- Major waterways, lakes, and rivers data obtained from U.S. Geological Survey hydrography digital line graphs. (Hand entered by system user).

- Major infrastructure locations, i.e., airports. (Hand entered by system user digitized data)

- Existing urban lands for the base year of 1990, general land use plans, light rail station locations, and slope data obtained from Digital Elevation Model USGS.

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Easy to use: UPLAN allows users to prepare and evaluate alternative suitability, growth, and allocation scenarios by specific prompts generated by the program.

- Customizable: UPLAN incorporates information provided by the users and applies its decision-tools to currently available GIS and non-GIS data, allowing the system to be customized to many different geographic areas and conditions.

- Integrated system: UPLAN provides an integrated software package that incorporates user-provided GIS and other data as a foundation and applies various evaluation/decision-tools (e.g., land use projection) to the underlying data. UPLAN uses currently available GIS data to prepare maps and reports showing the outcomes of alternative development scenarios on future land use patterns.

- The default six land use types (industrial; commercial hi-density and low density; and three residential densities) permit the evaluation of the impacts of the future land use pattern on runoff, water pollution, habitats, and costs from flooding and wildfires. Data grids can be a small as the data permit, generally 25 m grid cells.

Limitations

- Lack of sophisticated modeling: UPLAN provides a way for end users to visualize (as maps) the impacts of alternative development scenarios on future land use patterns. The users must provide existing urban land-use and digital land-use plans to the UPLAN system as inputs, as well as other normally available data layers. UPLAN does not provide the sophisticated modeling capability and/or theoretical basis to examine the interrelated factors of fiscal policies, and other planning decisions on the amount and type of future development and land use change that will occur. The attractiveness criteria are pseudo-economic, in that they represent land value and accessibility.

LEARNING MORE

Additional References

Not provided.

Availability of Preview Copies of the Model

Available for free from the model developer.

Case Studies

A paper on the Sacramento, CA application is available from the model developer.

Application Sites

- Sacramento, CA region
- Espanola region of New Mexico

UrbanSim

MODEL DEVELOPER(S): Paul Waddell: model design and project lead
Michael Noth, Alan Borning: software architecture

MAILING ADDRESS: Daniel J. Evans School of Public Affairs
University of Washington
P.O. Box 353055
Seattle, WA 98195-3055

CONTACT INFORMATION:
Phone: 206-221-4161
Fax: 206-685-9044
E-mail: pwaddell@u.washington.edu

WEB SITE: http://www.urbansim.org/

DOCUMENTATION: Available via the web site.

OVERVIEW

UrbanSim is a software-based system designed to be used for integrated planning and analysis of urban development, incorporating the interactions between land use, transportation, and public policy. It is designed to interface to existing travel modeling procedures, including both current four-step as well as newer activity-based travel models. It is currently being extended to address environmental impacts of development by simulating land cover, water demand and nutrient emissions. Specifically, the model:

- Simulates the key decision makers and choices impacting urban development; in particular, the mobility and location choices of households and businesses, and the development choices of developers;

- Explicitly accounts for land, structures (houses and commercial buildings), and occupants (households and businesses);

- Simulates urban development as a dynamic process over time and space, as opposed to a cross-sectional or equilibrium approach;

- Simulates the land market as the interaction of demand (locational preferences of businesses and households) and supply (existing vacant space, new construction, and redevelopment), with prices adjusting in response to short-term imbalances between supply and demand (vacancy rates);

- Incorporates governmental policy assumptions explicitly, and evaluates policy impacts by modeling market response;

- Is designed for high levels of spatial and activity disaggregation, currently using a 150 meter grid; and

- Addresses both greenfield development and redevelopment or intensification.

REQUIRED RESOURCES

Purchase Costs

None – may be downloaded for free at http://www.urbansim.org/.

Equipment Needs

UrbanSim requires a 333 MHz or higher computer with 128 MB of RAM, 2+ GBs of free hard drive space (can be less depending on study area grid resolution). It runs on Windows 95/98, Windows NT 4.0/2000, Linux or UNIX, using Java JKD 1.3.

Staff Requirements and Expertise

Calibration of the model requires knowledge of statistical software to perform multiple regression and logit model estimation using external econometric software such as Alogit or Limdep. Further work on calibration tools may make the use of external software unnecessary in the future. Use of the model requires land-use and transportation planning expertise and general computer experience. The user interface for the model is intended for relatively non-technical users.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

The land uses are user defined with typically 10 or more urban categories, but there is no internal limit on the number of urban or non-urban categories**.**

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)	✔[1,2]	

[1] Road tolls, parking fees, fuel and sales taxes, vehicle miles traveled, registration fees included through interaction with travel models.

[2] Includes fiscal policies such as Urban Growth Boundaries and regulations on development of environmentally sensitive lands.

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand	✔[1]	
Local Government Fiscal Conditions	✔[2]	
Availability of Open Space		
Environmental Quality	✔[3]	
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions	✔[4]	

[1] Included through interaction with travel models.

[2] The model provides the necessary outputs to estimate these impacts, but does not currently estimate them.

[3] Model components are currently being implemented to simulate land cover change, nutrient loading and water demand.

[4] The model can represent density, accessibility, socioeconomic mix, and land use mix. Any variable that can be measured and simulated for future years can be incorporated into the bid functions for housing and location choice. (Crime and school quality have not yet been included due to lack of model specifications to predict these values into the future, but could in principle be added based on relationships to other endogenous variables.)

Outputs Provided

All outputs are currently by zone, but can be made available at parcel or grid cell level.

Output	Format
Households by type (income, size, age of head, children, workers)	ASCII
Businesses and employment by type (sector)	ASCII
Acres by land use (real estate development type)	ASCII
Housing units and building square footage by type	ASCII
Prices of land, housing and commercial space by type	ASCII
Development projects simulated; new and redevelopment; conversion of land by type	ASCII

INFORMATION NEEDED TO RUN THE MODEL

Input	Format
Parcels	ArcView shape file and attribute table
Business establishments	ASCII
Household data from Census (STF3A and PUMS)	ASCII
Environmentally sensitive layers; e.g., wetlands, floodplains, high slopes, fault zones; and Urban Growth Boundaries or other policy boundaries	ArcView
Zones used in travel modeling	ArcView
Travel impedance from travel models (peak times and logsums)	ASCII

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Dynamic behavioral foundation is used that makes the model more transparent and explainable to users and decision-makers; reflects real-world processes that make the model easier to evolve and to interface to other process models such as environmental models.

- High degree of spatial resolution: Currently uses spatial grid of 150 meters for interface with environmental models such as land cover.

- Model and source code are entirely open source: They are freely available for use and modification, and can be downloaded from the web site. This is intended to facilitate collaborative use and further development.

- A visualization component has been designed into the model architecture, and is now operational. This provides integrated 2 and 3-dimensional mapping, in addition to charts and graphs for interpreting and comparing model results, and for diagnosis during model development and testing.

Limitations

- The model currently has high data requirements; data mining and synthetic data cleaning tools are currently being designed to facilitate working with messy data.

- The model has been recently developed, so experience is limited to current applications in Hawaii, Oregon, Utah and Washington.

- The model is being rapidly evolved, with the first major release based on a complete redesign of the software architecture in the second quarter, 2000.

LEARNING MORE

Additional References

Alberti, M. and P. Waddell. (forthcoming). An Integrated Urban Development and Ecological Simulation Model. *Integrated Assessments.*

L. Denise Pinnel, Matthew Dockrey, A.J. Bernheim Brush, and Alan Borning. (Forthcoming). Design of Visualizations for Urban Modeling. *Proceedings of VISSYM '00 – Joint Eurographics - IEEE TCVG Symposium on Visualization*, Amsterdam, May 2000.

Waddell, P. 2000. A behavioral simulation model for metropolitan policy analysis and planning: residential location and housing market components of UrbanSim. *Environment and Planning B: Planning and Design 2000*, volume 27(2): 247–263.

Waddell, P. (forthcoming). Between Politics and Planning: UrbanSim as a Decision Support System for Metropolitan Planning. Building Urban Planning Support Systems: Combining Information, Models, Visualization, Klosterman, R. and R. Brail eds. Center for Urban Policy Research.

Waddell, P. (forthcoming). Monitoring and Simulating Land Capacity at the Parcel Level. *Monitoring Land Supply with Geographic Information Systems: Theory, Practice and Parcel-Based Approaches*, Vernez-Moudon, A. and M. Hubner, eds., John Wiley & Sons, Inc.: New York.

Wegener, M., P. Waddell and I. Salomon. (forthcoming). Sustainable Lifestyles? Microsimulation of Household Formation, Housing Choice and Travel Behavior. *Proceedings of the National Science Foundation-European Science Foundation Conference on Social Change and Sustainable Transportation*, Berkeley, California.

Availability of Preview Copies of the Model
The UrbanSim model and user's manual are available at http://www.urbansim.org/.

Case Studies

- Bud Reiff
  Lane Council of Governments
  99 E. Broadway, Suite 400
  Eugene, OR 97401-3111
  Phone: 541-682-4283

- Peter Donner
  Governor's Office
  State of Utah
  116 State Capitol
  Salt Lake City, UT 84114
  Phone: 801-538-1027

Application Sites
- Honolulu, HI
- Eugene-Springfield, OR
- Greater Wasatch Front area (Salt Lake City), UT
- Puget Sound (Seattle, WA)

What if?

MODEL DEVELOPER(S): Developed by Dr. Richard E. Klosterman (as Community Analysis and Planning Systems, Inc.)

MAILING ADDRESS: Community Analysis and Planning Systems, Inc. (CAPS, Inc.)
78 Hickory Lane
Hudson, OH 44236-2707

CONTACT INFORMATION:
Phone: 330-650-9087
Fax: 330-650-9087
E-mail: Info@What-if.com

WEB SITE: www.What-if.com

DOCUMENTATION: Available in hard copy from model developer.

OVERVIEW

What if? was developed in 1997 to support communities in many aspects of the land-use planning process. What if? provides an integrated package of modules that enable users to: 1) conduct a land suitability analysis (Suitability Module), 2) project future land-use demand (Growth Module), and 3) allocate projected demand to the most suitable location (Allocation Module). What if? helps communities create alternative visions for their area's future by mapping alternative development patterns determined by local land development policies. Some of the policies and decisions What if? address include establishing various criteria to weigh the suitability of different locations for a particular land use, incorporating various land-use planning and zoning considerations and other allocation scenarios, and defining various growth scenarios.

REQUIRED RESOURCES

Purchase Costs

What if? is offered in two different contexts: 1) to provide support to communities, and 2) to provide a teaching tool in academic settings. The professional price is $2,495 for a single user; site licenses are available. The academic price of What if? is $250.00 for a single user; site licenses are available. A free demonstration CD for a real community can be obtained from CAPS, Inc..

Equipment Needs

What if? requires a 300 MHz Processor Intel Pentium II or above, 64 MB of RAM, 1 GB of free hard-disk space, a CD-ROM drive, a monitor that is SVGA compatible or better, and an MS Windows 95, 98, or NT 4.0 operating system, but no additional software. What if? is a fully self-contained software package.

Staff Requirements and Expertise

Use of What if? requires at the minimum an ability to work with ArcView and similar packages and a familiarity with local and use planning principles and procedures.

INFORMATION PROVIDED BY THE MODEL

Land Uses Addressed

What if? is capable of including any kinds of land-use data available from the community. Therefore, the actual land-use categories are defined by the community and can be as detailed or general as needed.

Urban Land-Use Categories	Yes?	No?
Residential	✔	
Commercial	✔	
Mixed-Use	✔	
Industrial	✔	
Other	✔	

Nonurban Land-Use Categories	Yes?	No?
Agricultural	✔	
Forest	✔	
Wetlands	✔	
Water	✔	
Preservation	✔	
Park Land	✔	

Questions Answered

(1) The model is capable of addressing the effects on land-use patterns from changes in the following community actions:

Community Action	Yes?	No?
Transportation Infrastructure	✔	
Local Zoning	✔	
City/County Master Plans	✔	
Local Fiscal Policies (e.g., fees, taxes, and incentives)		✔

(2) The model is capable of addressing the effects of changing land-use patterns on the following community characteristics:

Community Characteristic	Yes?	No?
Travel Demand		✔
Local Government Fiscal Conditions		✔
Availability of Open Space	✔	
Environmental Quality		✔

Community Characteristic	Yes?	No?
School Quality		✔
Crime		✔
Other Quality-of-Life Conditions		✔

Outputs Provided

Output	Format
Suitability Analysis Maps	GIS maps
Suitability Analysis Report	Report
Suitability Analysis Assumptions Report	Report
Growth Analysis Results Report	Report
Growth Analysis Assumptions Report	Report
Allocation Map	GIS map
Allocation Analysis Results Report	Report
Allocation Analysis Assumptions Report	Report

INFORMATION NEEDED TO RUN THE MODEL

The following inputs are desired, but not required to use, for What if?. The more detailed inputs the user can provide, the more robust analyses can be performed.

Input	Format
Standard GIS coverages including information on 1) natural features, 2) infrastructure plans, 3) existing land-use patterns, and 4) approved comprehensive plans or zoning ordinances. These layers are combined to create homogeneous land units (i.e., uniform analysis zones or UAZs).	ArcView, ArcInfo, and any other program that can generate files in ESRI shapefile format
Growth projections for number of households, assumed vacancy and loss rates, assumed housing densities per land use, employment by type, assumed employment density	Hand entered by system user
Alternative development scenarios that are pre-defined by the community using What if?	Hand entered by system user
Land-use classifications that are pre-defined by the community using What if?	Hand entered by system user
Infrastructure plans that are pre-defined by the community using What if?	Hand entered by system user

MODEL STRENGTHS AND LIMITATIONS

Strengths

- Easy to use: What if? allows users to prepare and evaluate suitability, growth, and allocation scenarios by using only Windows standard buttons, check boxes, and text boxes.

- Customizable: What if? incorporates information provided by the users and applies its decision tools to currently available GIS and non-GIS data, allowing the system to be customized to many different geographic areas and conditions.

- Integrated system: What if? provides an integrated software package that incorporates user-provided GIS and other data as a foundation and applies various evaluation/decision tools (e.g., suitability analysis and land-use projection and allocation) to the underlying data. What if? uses currently available GIS data to prepare maps and reports showing the outcomes of alternative development scenarios on future land-use patterns.

- Self-contained system: What if? is self-contained and requires no additional GIS or non-GIS software, although the user must be able to incorporate GIS layers (e.g., ESRI coverages or shapefiles) as input to the system. If desired, What if? inputs and outputs can be used with ArcView and any other package that works with ESRI shapefiles.

- Flexible data requirements: What if? is fairly easy to use with minimum data requirements. Users need only to provide inputs for existing land-use data to provide the basics for running What if? scenarios, although the system is able to accommodate more detailed information and data layers the study area may have available.

Limitations

- Lack of sophisticated modeling: What if? provides a way for end users to visualize (as maps) the impacts of alternative development scenarios on future land-use patterns. The users must provide the scenarios to the What if? system as inputs. What is? does not provide the sophisticated modeling capability and/or theoretical basis to examine the interrelated factors of transportation infrastructure, fiscal policies, and other planning decisions on the amount and type of future development and land-use changes that occur.

- What if? does not include measures of spatial interaction.

- Does not employ random utility or discrete choice theory to explain and project the behavior of various urban actors. Does not represent the interlinked markets for land, housing, nonresidential uses, labor and infrastructure, or provide any procedures for “market clearing” and price adjustment in the face of changes in demand and/or supply.

- Does not explicitly model the behavior of actors such as households, businesses, and developers.

LEARNING MORE

Additional References

Klosterman, Richard E. 1999. The What if? Collaborative Planning Support System. *Environment and Planning, B: Planning and Design*. 26: 393-408.

What if? Evaluation Copy of the software.

Availability of Preview Copies of the Model

May be obtained from the model developer.

Case Studies

- Professor Richard K. Brail
  Department of Urban Planning and Policy Development
  Rutgers University
  P.O. Box 5078
  New Brunswick, NJ 08903-5078
  Phone: (732) 932-2591, x731
  E-mail: rbrail@rci.rutgers.edu

- Ms. Jane Dembner, AICP, Principal
  LDR International, Inc.
  Quarry Park Place
  9175 Guilford Road, Suite 100
  Columbia, MD 21046-1861
  Phone: (410) 792-4360
  E-mail: dembner@ldr-int.com

Application Sites

- Hamilton County, OH
- Medina County, OH
- Summit County, OH

Appendix A
Land Use Models: Comparative Matrices

Exhibit A-1. Skills/Technical Expertise Comparative Matrix

Model Name	Target User Group	Technical Expertise for Usage (1 [none] – 3 [extensive]) [1]	Consultant Expertise Required?	Computer Skills for Usage (1 [general] - 3 [extensive]) [2]
CUF-1	Nontechnical community planning participants	2	No	3
CUF-2	Nontechnical community planning participants	2	No	3
CURBA	Land use planners, policy makers, and environmentalists	1	No	2
DELTA	Politicians, policy makers, planners	3	Yes	1
DRAM/EMPAL	Regional transportation and land-use planners	3	Yes, cost to purchase includes consultant services	2
GSM	Land Resource Managers	2	No	2
INDEX	Community planning participants	3	Yes	2
IRPUD	Regional transportation and land-use planners, researchers	3	Yes	1
LTM	Watershed stakeholders (resource managers, landowners, planners)	3	Yes	3
LUCAS	Land resource managers	3	Yes	3
Markov	Demographers, residential planners, developers, policy makers	1	No	2
MEPLAN	Planners, transportation engineers, economists	2	No	1
METROSIM	Planners, transportation engineers, economists	1	Yes	1
SAM-IM	Land-use planners and forecasters	1 (but there is a learning curve/training required)	Yes	2
SLEUTH	Academic and government researchers, planners	2	No	2
Smart Growth INDEX	Community planning participants	2	No	2
Smart Places	Planners (land use, transportation, environmental), community groups	1	No	1
TRANUS	Transportation and land use planners and academics	2	No	2

Model Name	Target User Group	Technical Expertise for Usage (1 [none] – 3 [extensive]) [1]	Consultant Expertise Required?	Computer Skills for Usage (1 [general] - 3 [extensive]) [2]
UGrow	Academic and government researchers, planners, policy makers	1	No	1
UPLAN	Nontechnical community planning participants	2	No	2
UrbanSim	Planners (land use, transportation, environmental), community groups	2	No	1
What if?	Nontechnical community planning participants	2	No	1

[1] (1) No experience required; (2) land use experience; (3) land use modeling experience

[2] (1) General computer experience; (2) familiarity with specific software applications; (3) programming skills

Exhibit A-2. Hardware Comparative Matrix

Model Name	Type Computer Required	CPU Required (MHz)	Minimum Disk Space Required/RAM (MB)	Peripherals Needed?
CUF-1	workstation	Not specified	Not specified	Not specified
CUF-2	Sun Sparc or PC	300	2 GB/32	Color monitor
CURBA	PC	300+	1GB/32	Color monitor
DELTA	PC	Pentium 200	Depends on model dimensions	Color monitor recommended
DRAM/EMPAL	PC	Pentium	Not specified	Color monitor and color printer
GSM	PC	500	Not specified/128+	Color plotter
INDEX	PC	200	150/64	Color monitor and color printer
IRPUD	IBM Pentium III PC	300+	4+ GB/128+	Color monitor with minimum resolution of 1024x768 and color printer
LTM	Sun Sparc or PC	300	Not specified/256	Color monitor with minimum resolution of 1024x768 and color printer
LUCAS	UNIX-based workstation(e.g., Sun Sparc station 10)	Not specified	Not specified	Color monitor and color printer
Markov	Any	Not specified	Not specified	Not specified
MEPLAN	PC	200+	500/64	Color monitor
METROSIM	Any	300+	Not specified/128	Color monitor
SAM-IM	PC	400	2 GB/128+	Color monitor and color printer
SLEUTH	PC, workstation, or mainframe	Not applicable	Not applicable	None
Smart Growth INDEX	PC	300	500/64	Color monitor (1024 x 768 min. resolution) and color printer
Smart Places	Pentium PC	120	1GB/32	CD-ROM drive required; color monitor recommended
TRANUS	PC	Not specified -- the faster the better	30/64	Color monitor required; colored printer and a digitizer are useful

Model Name	Type Computer Required	CPU Required (MHz)	Minimum Disk Space Required/RAM (MB)	Peripherals Needed?
UGrow	PC	Not specified - a minimal amount is necessary	Not specified - a minimal amount is necessary	None
UPLAN	PC	300	Several hundred/32	Color monitor required; 21" monitor, color printer, and plotter are recommended.
UrbanSim	Any	333	2 GB/128	None
What if?	PC	300	1 GB/64	None

Exhibit A-3. Software Comparative Matrix

Model Name	Operating System	Program Compiler Needed? (Y/N)	Data Management Tools	Statistical Software Needed? (Y/N)	GIS Software Needed? (Y/N)	Other
CUF-1	UNIX	N	Not specified	Y; SPSS	Not specified	Not specified
CUF-2	MS Windows 95, Sun Soloris	N	Not specified	Y; SAS	Y; ArcInfo or ArcView	Not specified
CURBA	MS Windows	N	Not specified	Y; SAS or SPSS	Y; ArcView	None
DELTA	MS DOS (either under DOS mode or Windows 95/ 98)	N	Spreadsheets and data bases highly recommended	Not specified	Highly recommended	DBOS memory manager (distributed with DELTA model)
DRAM/EMPAL	MS Windows 95/98 or NT	N	Spreadsheets and data bases	N	Y; ArcView	Developer participation
GSM	MS Windows NT or UNIX	N	Paradox or Oracle	N	Y; ArcInfo or other GIS	None
INDEX	MS Windows 95 or NT	N	None	N	Y; ArcView	None
IRPUD	MS Windows NT	Y; FORTRAN, C, C++	None	Y	Y; ArcInfo	None
LTM	MS Windows NT or Sun Soloris	Y	Spreadsheets and data bases	Y; S-Plus and SAS	Y; ArcInfo or ArcView	Stuttgart Neural Network Simulator
LUCAS	MS Windows with OSF/Motif toolkit	Y	Spreadsheets	Y; SAS	Y; GRASS	Not specified
Markov	Any	Not specified	Recommended for users	Recommended for developers	Not specified	Not specified
MEPLAN	MS Windows NT	N	Any for data preparation; MapInfo 4.5 and ACCESS 95 for MEPLUS	Y: any will do	Y	Any word processor; MapInfo is needed if MEPLUS is being used to process MEPLAN results
METROSIM	Any; UNIX preferred but not required	Y; FORTRAN or C	Excel or Access	Y; SAS or SPSS	Y; ArcInfo or MapInfo	None

Model Name	Operating System	Program Compiler Needed? (Y/N)	Data Management Tools	Statistical Software Needed? (Y/N)	GIS Software Needed? (Y/N)	Other
SAM-IM	MS Windows NT or 95	N; although Visual BASIC is helpful	None	Y; for calibration only, if want to do it	Y; ArcView 3.2 with the Spatial Analyst Extention	None
SLEUTH	UNIX	Y; gnu C compiler (gcc)	Not specified	Not specified	Not specified	X-Windows required for graphical version
Smart Growth INDEX	MS Windows 95 or NT	N	None	N	Y; any local system	None
Smart Places	MS Windows 95/ 98 or higher	N	None	N	Y; ArcView	None
TRANUS	MS Windows 95, 98 or NT; or Mac with Windows emulation	N	Windows-based spreadsheets, word processors, and presentation programs very useful, but not essential	SAS or SPSS can be useful, but not essential	ArcView or ArcInfo can be very useful, but not essential	Logit calibration program can be useful (e.g., Alogit, Hielow)
UGrow	MS Windows 95	N	None	N	Y; ArcInfo, ArcView	Powersim modeling software
UPLAN	Windows 95/98 or NT	N	Excel for data exchange with other models.	Y; SAS for data exchange with other models.	Y; ArcView (need ArcInfo to prepare data layers for local application)	None
UrbanSim	MS Windows 95/98, Windows NT 4.0/2000, Linux, or UNIX	Y; JAVA JKD 1.3	Not specified	Not specified	Not specified	Not specified
What if?	MS Windows 95/ 98 or NT 4.0	N	None	N	N	None

Exhibit A-4. Cost Comparative Matrix

Model Name	Purchase Cost	Operating Cost	Maintenance Cost	Training Costs
CUF-1	Not available for "off-the-shelf" purchase. Contact developer.	Not specified	Not specified	Not specified
CUF-2	Not available for "off-the-shelf" purchase. Contact developer.	Not specified	Not specified	Not specified
CURBA	Not specified	Not specified	Not specified	Not specified
DELTA	Contact developer	Contact developer	Contact developer	Contact developer
DRAM/EMPAL	$30,000–$60,000 which includes training and consulting services	Not specified, but requires about 1 senior modeler with junior support	Not specified	Included with purchase cost
GSM	Not applicable – not yet adapted as an application for distribution	Not applicable – not yet adapted as an application for distribution	Not applicable – not yet adapted as an application for distribution	Not applicable – not yet adapted as an application for distribution
INDEX	$15,000– $75,000	Typically 1-8 person hours	Typically 4-6 person weeks	Typically 2-3 person days
IRPUD	Contact developer	Contact developer	Contact developer	Contact developer
LTM	Contact developer (likely no cost)	Contact developer	Contact developer	Contact developer
LUCAS	No cost	Not specified	Not specified	Not specified
Markov	No cost	No cost	No cost	No cost
MEPLAN	$25,000	Not available	10% of purchase price annually	About $640 per day
METROSIM	$20,000-$30,000	$2,500 for three initial runs (negotiable). Full reports are included.	$5,000 - $10,000/yr	$10,000 one-time
SAM-IM	Contact developer (average $30,000 - $100,000 total cost)	Contact developer	Contact developer	Contact developer
SLEUTH	No cost	Not specified	Not specified	Not specified
Smart Growth INDEX	Initial version available at no cost through U.S. EPA Urban and Economic Development Division; enhanced versions currently under development	Typically 1–8 person-hours; cost dependent upon salary rate for staff or consultant labor.	Typically 4–6 person-weeks/yr.; cost dependent upon salary rate for staff or consultant labor.	Typically 2–3 person-days; cost dependent upon salary rate for staff or consultant labor.
Smart Places	Contact developer	Contact developer	Contact developer	Contact developer

Model Name	Purchase Cost	Operating Cost	Maintenance Cost	Training Costs
TRANUS	$7,500	Included in purchase cost	1-year guarantee included in purchase cost	$8,000 plus expenses for 2-week, full-time course
UGrow	Software is free. However, to be useful, the developer must adapt the model which can cost $30,000 - $200,000.	Not specified	Not specified	Not specified
UPLAN	No cost	Not specified	Not specified	Not specified
UrbanSim	No cost	Not specified	Not specified	Not specified
What if?	For a single user, the professional price is $2,495 and the academic price is $250. Professional and academic site licenses are available.	No cost	$1,000/year	Not available

Exhibit A-5. Urban Land Use Categories Addressed Comparative Matrix

Model Name	User Defined? Limits?	Urban Land-Use Categories				
		Residential	Commercial	Mixed Use	Industrial	Other
CUF-1	No; limited to residential	Yes	No	No	No	Open space
CUF-2	No; four "new" land uses and three redevelopment land uses	Single-family; multi-family	Yes	Not considered separately from residential or commercial land uses	Yes	Residential, commercial, and industrial redevelopment
CURBA	No; all urban development considered together					
DELTA	Yes; no limitations	User defined, so all potential urban categories	User defined, so all potential urban categories	User defined, so all potential urban categories	User defined, so all potential urban categories	User defined, so all potential urban categories
DRAM/ EMPAL	No	By household income	By employment type	No	By employment type	Vacant developable, vacant undevelopable
GSM	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
INDEX	Yes; typically 6–30 categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
IRPUD	No	Yes	Yes	Yes	Yes	Yes
LTM	Yes; can accommodate up to 8 land uses	By density	No	No	No	No
LUCAS	Yes	By density	Yes	No	No	No
Markov	Yes; residential sector only	Owner/renter, Single/ multi-family, Size of home	No	No	No	No
MEPLAN	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
METROSIM	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories

Model Name	User Defined? Limits?	Urban Land-Use Categories				
		Residential	Commercial	Mixed Use	Industrial	Other
SAM-IM	Yes; limit of 40 categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
SLEUTH	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
Smart Growth INDEX	Yes; typically 6–30 categories	By density	Office, retail, service	Can be customized to accommodate user's data	Light/heavy, Brownfields, Enterprise zones	Can be customized to accommodate user's data
Smart Places	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
TRANUS	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
UGrow	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
UPLAN	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
UrbanSim	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
What if?	Yes; can accommodate up to 15 different land uses	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories

Exhibit A-6. Non-Urban Land Use Categories Addressed Comparative Matrix

Model Name	User Defined? Limits?	Nonurban Land-Use Categories					
		Agriculture	Forest	Wetlands	Water	Preservation	Parkland
CUF-1	Yes; determined by availability of input map layers	Yes	Yes	Yes	Yes	As identified by user	Yes
CUF-2	Yes; determined by availability of input map layers	Yes	Yes	Yes	Yes	As identified by user	Yes
CURBA	Yes; determined by availability of input map layers	Yes	Yes	Yes	Yes	As identified by user	Yes
DELTA	No	No	No	No	No	No	No
DRAM/EMPAL	Yes	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
GSM	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
INDEX	Yes; typically 6–30 categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
IRPUD	No	Yes	Yes	No	Yes	No	No
LTM	Yes; can accommodate up to 8 land uses	Yes	Yes	Yes	Yes	No	Yes
LUCAS	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Markov	No	No	No	No	No	No	No
MEPLAN	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories

Model Name	User Defined? Limits?	Nonurban Land-Use Categories					
		Agriculture	Forest	Wetlands	Water	Preservation	Parkland
METROSIM	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
SAM-IM	Yes; limit of 40 categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
SLEUTH	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
Smart Growth INDEX	Yes; typically 6–30 categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
Smart Places	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
TRANUS	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
UGrow	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
UPLAN	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
UrbanSim	Yes; no limitations	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories
What if?	Yes; can accommodate up to 15 land use types	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories	User defined, so all potential categories

Exhibit A-7. Impacts of Community Decisions on Land-Use Patterns Comparative Matrix

Model Name	Transportation infrastructure	Local zoning	City & county master plans	Other local fiscal policies	Developer impact fees	Property taxes	Municipal sewer and water fees	Subsidies	Road tolls	Parking fees	Fuel and sales taxes	VMT	Registration fees
CUF-1		✓	✓		✓		✓						
CUF-2	✓	✓	✓		✓		✓						
CURBA	✓	✓	✓										
DELTA	✓	✓	✓						✓[1]	✓[1]	✓[1]	✓[1]	✓[1]
DRAM/ EMPAL[2]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
GSM	✓[3]	✓	✓	✓[4]									
INDEX		✓	✓										
IRPUD										✓	✓	✓	✓
LTM	✓		✓										
LUCAS	✓	✓	✓										
Markov		✓	✓										
MEPLAN	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
METROSIM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAM-IM	✓	✓	✓										
SLEUTH	✓	✓	✓	✓									
Smart Growth INDEX	✓	✓	✓										
Smart Places[5]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TRANUS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
UGrow													
UPLAN	✓	✓	✓		✓	✓	✓	✓		✓			
UrbanSim	✓	✓	✓	✓					✓[6]	✓[6]	✓[6]	✓[6]	✓[6]
What if?	✓	✓	✓										

[1] Yes, but only if these can be modeled in an associated transport model integrated with DELTA.

[2] Any may be addressed by DRAM/EMPAL when linked to the right model. Without linking, most can not be.

[3] Under development

[4] No fiscal policies are pre-set in the model. However, if the user can provide specifications on the impact of the revenue source, then the policy can be incorporated.

[5] Smart Places can be customized to evaluate the impact of changes in land-use patterns based on user-supplied criteria.

[6] Included only through interaction with travel models.

Exhibit A-8. Impacts of Land-Use Patterns on Community Characteristics Comparative Matrix

Model Name	Travel demand	Changes in infrastructure costs	Changes in local tax revenue	Other fiscal impacts	Open Space	Nutrient loading	Increases in storm water runoff	Other nonpoint source water pollution	Other water quality impacts	Changes in criteria pollutants	Changes in greenhouse gasses	Other air quality impacts
CUF-1		✓			✓	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]
CUF-2					✓	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]
CURBA						✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]
DELTA	✓[2]									✓[2]	✓[2]	✓[2]
DRAM/ EMPAL	✓	✓	✓	✓	✓	✓	✓			✓	✓	
GSM	✓[3]				✓	✓	✓		✓			
INDEX						✓	✓			✓	✓	
IRPUD	✓				✓							✓[4]
LTM									✓			
LUCAS					✓							
Markov		✓	✓	✓								
MEPLAN	✓	✓	✓	✓	✓[5]					✓	✓	
METROSIM[6]	✓	✓	✓	✓	✓					✓	✓	
SAM-IM	✓				✓							
SLEUTH			✓[7]	✓[7]	✓[7]	✓[7]	✓[7]	✓[7]	✓[7]	✓[7]	✓[7]	✓[7]
Smart Growth INDEX	✓				✓	✓	✓		✓	✓		
Smart Places[8]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TRANUS	✓	✓	✓	✓	✓					✓	✓	✓
UGrow	✓				✓						✓	
UPLAN	✓[9]	✓	✓	✓	✓	✓[10]		✓[10]		✓	✓	
UrbanSim	✓	✓	✓	✓	✓	✓						
What if?					✓	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]

[1] Model does not directly address these issues. However, model results may be applicable as inputs into appropriate impact models to determine effects of urbanization and land use change on other systems.

[2] When DELTA is integrated with transport and environmental models.

[3] Currently under development.

[4] The IRPUD can forecast CO_2 emissions as a function of forecasting transportation-related indicators. Environmental submodels that calculate traffic noise and air pollution indicators are under development.

[5] Open space is addressed in MEPLAN only when linked to the right model.

[6] Effects on air and water pollution can be treated if METROSIM is interfaced with any add-on environmental package.

[7] Any fiscal or environmental impact which can be estimated as a function of urbanized area could be developed for the output of SLEUTH, but the model does not do so directly.

[8] Smart Places can be customized to evaluate these impacts based on user-specified criteria.

[9] UPLAN does not address travel demand directly but can when linked to any travel model.

[10] UPLAN is under development to address nutrient loading or sedimentation in surface waters and other nonpoint pollution.

Exhibit A-9. Model Utility and Integration Comparative Matrix

Model Name	Relative Ease of Linking to Other Models (1 [easy] – 3 [hard]) [1]	Relative Ease of Transferring to Other Locations (1 [easy] – 3 [hard]) [1]	Number of Locations to Which Model Has Been Applied[2]
CUF-1	2	2	1
CUF-2	2	2	1
CURBA	2	2	>10
DELTA	2	2	6
DRAM/EMPAL	2	2	40+
GSM	2	2	350
INDEX	2	2	>10
IRPUD	2	2	1
LTM	1 (environmental process models)	2	1-5
LUCAS	3	2	1-5
Markov	2	2	>10
MEPLAN	2	2	25+
METROSIM	1–2 (depends on package linked to)	1	6 (includes earlier versions)
SAM-IM	2	2	2
SLEUTH	2	2	13
Smart Growth INDEX	2	1	18
Smart Places	2	2	1 (35+ other sites have license agreements to use)
TRANUS	2	1	35+
UGrow	3	2	6
UPLAN	2	2	2
UrbanSim	2	2	4
What if?	2	2	3

[1] (1) Effortless; (2) feasible with a manageable amount of modifications required; (3) impossible or impractical, would require a great deal of effort.

[2] The spacial scales of the locations vary and include regions/watersheds, large and small cities/ towns, and neighborhoods.

Exhibit A-10. Basic Operational Characteristics Comparative Matrix

Model Name	Model Type	Thematic Scope	Underlying Math Structure	Operational Methods	Technical Expertise for Calibration (1 [general] – 3 [extensive]) [1]	Relative Ease of Calibration (1 [easy] – 3 [hard])[1]	Measure of Confidence or Goodness of Fit? (Y/N)
CUF-1	• Urban growth	• Urban development evaluation and simulation	• Deterministic	• Regression	2	3	N
CUF-2	• Land use change	• Urban development evaluation and simulation	• Deterministic • Stochastic	• Multinominal logit • Regression	3	3	Y
CURBA	• Urban growth	• Urban growth • Environmental and ecological quality	• Stochastic	• Binomial logit • Regression	2	2	Y
DELTA	• Urban economic/ land use market	• Urban and regional economics	• Deterministic	• Markov chains • Multinominal logit methods • Cobb-Douglas utility functions • Elasticity-based responses • Matrix adjustment methods	3	3	N
DRAM/ EMPAL	• Urban statistical • Spatial interaction • Aggregate logit	• Housing • Employment	• Stochastic	• Multinominal logit • Regression	3	1	Y
GSM	• GIS	• Development • Resource Land • Conservation • Watershed Management	Not specified	Not specified	3	2	Not applicable

Model Name	Model Type	Thematic Scope	Underlying Math Structure	Operational Methods	Technical Expertise for Calibration (1 [general] – 3 [extensive]) [1]	Relative Ease of Calibration (1 [easy] – 3 [hard])[1]	Measure of Confidence or Goodness of Fit? (Y/N)
INDEX	• GIS • Urban Impact	• Land use • Transportation • Housing • Employment • Natural Environment	• Deterministic	• Causal inference • Correlation • Linear programming • Network analysis • Time-series	2	2	Not applicable
IRPUD	• Travel demand model • Urban economic/land use market models	• Transportation • Economics • Technological impacts	• Probabilistic • Stochastic	• Markov chains • Multinominal logit methods • Microsimulation • Variant of inclusive value method	3	3	Not specified
LTM	• GIS • Urban Impact • Neural network	• Land use • Ecology integrity • Economic sustainability	• Empirical	• Markov chains • Regression • Artificial neural networks	3	3	Y
LUCAS	• GIS	• Land use • Environmental impacts • Socioeconomic	• Stochastic	• Time series	3	3	Y
Markov	• Markov chain	• Residential housing • Mobility	• Stochastic	• Linear programming • Markov chains/ transition matrices • Multinominal logit • Regression	3	2	Y
MEPLAN	• Travel demand • Urban economic/land use market • Hedonic	• Spatial economic-based input/output	• Stochastic	• Multinominal logit • Network analysis	3	2	Y

Model Name	Model Type	Thematic Scope	Underlying Math Structure	Operational Methods	Technical Expertise for Calibration (1 [general] – 3 [extensive]) [1]	Relative Ease of Calibration (1 [easy] – 3 [hard])[1]	Measure of Confidence or Goodness of Fit? (Y/N)
METROSIM	• Travel demand • Markov chain • Urban economic/land use market • Hedonic • Discrete choice method	• Land use • Metropolitan economy	• Deterministic • Stochastic • Empirical/semi-Empirical	• Markov chains • Multinominal logit methods • Network analysis • Regression • Time-series • Dynamic economic general equilibrium analysis	1	1-2	Y; if desired
SAM-IM	• GIS	• Urban growth • Transportation • Economics • Environmental impacts	• Deterministic • Stochastic • Empirical/semi-Empirical	• Cellular automata • Multinominal logit methods • Regression	1 (but there is a learning curve/training required)	3	N; model doesn't provide but statistical packages used in the calibration do
SLEUTH	• Cellular automata	• Urban growth • Environmental impacts	• Stochastic	• Cellular automata • Time-series • Monte Carlo imaging	3	2	Y
Smart Growth INDEX	• GIS • Urban impact • Travel demand	• Land use • Transportation • Housing • Employment • Infrastructure • Environment	• Deterministic	• Causal inference • Correlation • Linear programming • Multinominal logit • Network analysis • Time series	3	1	N
Smart Places	• GIS	• Land-use • Economics • Environmental impacts	• Deterministic	• Causal inference	2	2 (calibration is not required)	N

Model Name	Model Type	Thematic Scope	Underlying Math Structure	Operational Methods	Technical Expertise for Calibration (1 [general] – 3 [extensive]) [1]	Relative Ease of Calibration (1 [easy] – 3 [hard])[1]	Measure of Confidence or Goodness of Fit? (Y/N)
TRANUS	• GIS • Urban impact • Travel demand • Urban economic/land use market • Hedonic	• Transportation • Economics • Environmental impacts	• Stochastic	• Causal inference • Multinominal logit • Network analysis • Time-series • Discrete choice analysis • Decision theory • Random utility theory • Input-output analysis • Algorithms	3	2	Y
UGrow	• Systems dynamics	• Private and public infrastructure • Land use • Transportation	• Deterministic	Casual inference System dynamics	3	3	N
UPLAN	• GIS • Urban impact	• Land-use evaluation and change analysis	• Deterministic	Not specified	Not applicable	Calibration not required	N
UrbanSim	• Random utility logit • Urban economic/ land use market • GIS • Hedonic	• Land-use • Transportation • Economics • Environmental impacts	• Empirical/semi-Empirical	• Expert systems • Multinominal logit • Regression • Monte Carlo simulation	3	2	Y
What if?	• GIS	• Land-use evaluation and change analysis	• Deterministic	• Mapping (GIS)	Not applicable	Calibration not required	N

[1] (1) Parameters can be recalibrated using options embedded in the software for the model.; (2) Parameters can be recalculated using methods/instruction cited in model documentation or by altering input files; (3) Parameters can only be recalibrated using original programming with no guidance from the model developers (e.g., no documentation), or parameters are hardwired and cannot be recalibrated.

Exhibit A-11. Spatial And Temporal Capabilities Comparative Matrix

Model Name	Spatial Resolution	Spatial Extent	Temporal Resolution	Temporal Extent (Future and Past)
CUF-1	User defined, but generally 1 acre or larger	Customized for user needs	5 year	5+ years into the future
CUF-2	One-hectare(100x100m) grid cells	Customized for user needs	5 year	5+ years into the future
CURBA	One-hectare(100x100m) grid cells	Scalable and can be customized for user needs	User defined	User defined into the future
DELTA	User defined, but intended to work with strategic rather than very detailed zones	Customized for user needs, typically applicable to cities with populations of 250,000+	1 year increments recommended, but can be longer	User defined into the future
DRAM/EMPAL	Census tracts for some data; regional level for economic data	Customized for user needs, but preferably metropolitan areas with a population of at least 200,000	5 year	40 years into the future
GSM	User defined	User defined	User defined	User defined
INDEX	User defined	User defined (depends on the extent of local GIS)	Yearly	User defined (depends on available data)
IRPUD	Revised version of model will allow about 300 zones.	Local or regional level	User defined	User defined into the future
LTM	Parcel (30m x 30m), plat (100m x 100m), block (300m x 300m), and local (1 km x 1km)	User defined (precedence given to watersheds)	5 or 10 year	20–50 years into the future; can hindcast into the past
LUCAS	User defined; a single grid cell or pixel may be defined to 90m x 90m.	User defined	5 year	100 years into the future
Markov	One or more households	Not applicable	Usually 3–5 years	Limited by Census data
MEPLAN	User defined; can vary from a few hundred meters to whole countries, depending on study	User defined; has been used to represent cities in regional context to entire countries	User defined, but five years is common	User defined
METROSIM	User defined	User defined	Yearly or some aggregation of years such as 2 years, 5 years or decades	Any number of time periods can be accommodated, but more than 30 not recommended
SAM-IM	User defined	User defined	User defined	User defined into the future
SLEUTH	User defined	User defined	Yearly	As far into the past or future as available data will allow
Smart Growth INDEX	User defined between 5–100 acres	Community or region, depends on the extent of local GIS	Yearly	20 years into the future

Model Name	Spatial Resolution	Spatial Extent	Temporal Resolution	Temporal Extent (Future and Past)
Smart Places	User defined	User defined	Not applicable	Not applicable
TRANUS	User defined, but too many zones can become a nuisance	User defined	User defined, but 5 years is common	User defined
UGrow	Depends on available GIS data	User defined	Yearly	1,950–2,100
UPLAN	Low density residential represented in 10 acre parcel size (200 m cells),while all other land uses are represented by ½ acre parcel size (50 m cells)	User defined	User defined	User defined
UrbanSim	User defined, current application have used 150 m resolution	User defined	Yearly, but option for arbitrary time intervals.	User defined into the future
What if?	User defined, but best suited for sizes larger than single parcel	User defined	User defined	Up to 4 projection periods

Appendix B

Land Use Models: Technical Fact Sheets

California Urban Futures (CUF) Model: CUF-1
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

CUF-1 may be customized to meet study area needs of the end user. The typical county in the San Francisco Bay area simulation had 30,000 to 50,000 DLUs. DLUs range in size from one acre to several hundred acres. The spacial scale is based on the resolution of the data provided by the end user, but it is generally one acre or larger. The flexibility of the CUF model allows it to be used at a regional or county level. Because the CUF model allocates growth on a site-by-site basis, it is well suited to examining environmental impacts associated with development alternatives.

Temporal Resolution and Extent

The CUF-1 model generates 5-year population growth forecasts and maps.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

- Requires population trend data to calibrate growth models.
- Requires development cost data to estimate potential profitability of site development.

Input Pre-Processing Requirements

Input data may possibly require pre-processing, but pre-processing requirements not specified.

Model Assumptions

The CUF model enables users to build their own set of assumptions about land use suitability; projected growth demands (future population); and regulatory and investment policies.

Setting Parameters

Several modules of CUF require the end user to set various input parameters to evaluate alternative scenarios. The required parameters are listed as follows:

- The Bottom-up Population Growth Submodel
  - Dependent variable: Population levels by city or county five years ago
  - Independent variables: City size class (i.e., very small, small, medium, medium large, and large); whether the city or county has a population, housing, or development cap; whether the city is prevented from expanding because it is land-locked (by neighboring communities) or water-locked; gross population density by city for the previous five-year period; a variable of current statewide population weighted by the land area of each city in the previous five-year period; the numerical

change in “basic” employment in the county during the previous five years; and, each county’s share of region-wide population growth (lagged five years) and weighted by the state population in the current year.

- The Spatial Database
  - A series of user-defined map layers that describe attributes such as the environmental, land-use, zoning, current density, and accessibility characteristics of the sites in the study region

- The Spatial Allocation Submodel
  - Several parameters related to the total profit a home builder would expect to realize on the construction of as many new homes as could be accommodated on a particular DLU, including new home sale price; raw land price; hard construction costs; site improvement costs; service extension costs; development, impact, service hookup, and planning fees; delay and holding costs; and extraordinary infrastructure capacity costs, exactions, and impact mitigation costs

Comparing Scenarios

The CUF model addresses multiple scenarios, allowing the user to determine the impacts of alternative growth policies. For example, three regional growth policy scenarios for the Northern California Bay Region were evaluated using the model: a business as usual scenario, a maximum environmental protection scenario, and a compact cities scenario. The scenarios are user defined and used by the CUF model to determine future land use patterns.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

Not specified.

NEXT STEPS FOR MODEL DEVELOPMENT

A second generation of the CUF model (“CUF-2") has been developed to address several of the limitations discovered in the original CUF-1 model. See the separate evaluation of the CUF-2 model in this series for more information.

California Urban Futures (CUF) Model
Second Generation: CUF-2
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The CUF-2 model can be customized to meet study area needs of the end user. The basic units of analysis (DLUs) consist of one-hectare (100 m x 100 m) grid cells. The flexibility of the CUF-2 model allows it to be used at a regional or county level. Because the CUF model allocates growth on a site-by-site basis, it is well suited to examining environmental impacts associated with development alternatives.

Temporal Resolution and Extent

The CUF-2 model generates 5-year population growth forecasts.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

CUF-2 incorporates a statistical model. User must initially calibrate a series of multi-nomial logit parameters which they can then re-use or modify. Testing of alternative infrastructure investments may require additional digitizing or GIS preparation.

Input Pre-Processing Requirements

Input data may possibly require pre-processing, but pre-processing requirements not specified.

Model Assumptions

The CUF-2 model enables users to build their own set of assumptions about land use suitability; projected growth demands (future population); and regulatory and investment policies.

Setting Parameters

CUF-2 initially requires the user to statistically calibrate the parameters of a non-ordinal, multi-nomial logit model of urban land use change. Once calibrated, parameters may be re-used and modified. Policy simulations are tested using a “check list” of constraints and policies.

Comparing Scenarios

The CUF model addresses multiple scenarios, allowing the user to determine the impacts of alternative growth policies. The scenarios are user defined and used by the model to determine future land use patterns.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

Not specified.

NEXT STEPS FOR MODEL DEVELOPMENT

Not specified.

California Urban and Biodiversity Analysis Model (CURBA)
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The CURBA model is scalable and can be customized to meet study area needs of the end user. CURBA's basic unit of analysis and minimum mapping unit is one-hectare (100 m by 100 m). The typical study area is one or more counties.

Temporal Resolution and Extent

CURBA's pilot simulations were run for 15 years (1995-2010). The pilot simulations did not have intermediate time steps. Instead, the model showed changes from the initial time period (1995) and the end point of the simulation (2010). Simulations may be run with different end points, however.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

Requires external population or household growth projections reported at the county or municipal level.

Input Pre-Processing Requirements

Input data may possibly require pre-processing. Certain data may require reformatting to accommodate the GIS.

Model Assumptions

CURBA assumes that factors and forces that determined past urban growth patterns and trends will also determine future patterns and trends. All urban land uses are assumed to be homogeneous.

Setting Parameters

CURBA initially requires the user to statistically calibrate the parameters of a binomial logit model of urban growth. Once calibrated, parameters may be re-used and modified. Policy simulations are tested using a "pick list" of constraints and policies.

Comparing Scenarios

CURBA allows the user to address multiple scenarios by changing various assumptions and saving the results of alternative scenarios for comparison.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

Model is currently being refined to reduce the effects of spatial auto-correlation.

DELTA
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The DELTA model contains an urban level and a regional level. The urban DELTA model typically applies to cities with a population of 250,000 or greater. The regional DELTA model applies to areas containing a number of distinct sub-regional economies (e.g., labor market areas).

The model is intended to work with strategic areas, versus very detailed areas. The spatial resolution of the model is based on the resolution of the data provided by the user.

Temporal Resolution and Extent

DELTA can be run for any historical period for which data are available. It can be run as far into the future as the user requires, though accuracy clearly diminishes with longer time horizons.

The model developer recommends that DELTA's scenarios run in a yearly increment. The transport model integrated with DELTA can be run with longer increments.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The DELTA package is intended to assist in the testing and evaluation of a wide range of transport and land use policies. DELTA itself is a land-use modeling system; it is designed to interface with any appropriate transport model to create a full land-use/transport interaction model. Existing transport models may be used with the DELTA model.

The full DELTA package consists of the following:

- An **urban level**, containing sub-models for:
  - Urban development processes;
  - Changes in urban area quality;
  - Demographic (household) transitions and economic growth;
  - Car ownership;
  - Location/real estate market (e.g., location of households and jobs, real estate values, and occupation/vacancy); and
  - Labor market and commuting.

- A **regional level**, containing sub-models for:
  - Migration between urban areas;
  - Investment levels/locations; and
  - Production and trade.

Full DELTA applications contain both urban and regional levels. Partial applications can be built at either the urban or regional level. The system offers a high level of flexibility for more or less detailed model designs (e.g., few or many categories of households and of employment). As with all land use models, much of the work associated with using the DELTA system is related to collecting local data and testing the "realism" of the model under local conditions.

The DELTA package is designed to operate in short (e.g., 1- to 2-year) time increments. Land uses respond to transport change, modeled in the chosen transport model, as well as to land use policies that are modeled within DELTA. Outputs from DELTA – particularly numbers of residents and numbers of jobs – provide inputs to the transport model, which can be run at the end of each DELTA time increment or at less frequent intervals.

Input Pre-Processing Requirements

DELTA may require input pre-processing, depending on the condition and format of the user's data. All inputs must be in DELTA-specific, fixed formats (e.g., fixed-format ASCII files).

Model Assumptions

The model assumes that development is new construction. Redevelopment and reuse/change of use are not easily captured by the existing DELTA system. With the exception of development, DELTA enables users to build their own set of assumptions about land use parameters.

Setting Parameters

Behavioral coefficients for each sub-model and variables to determine demographic and economic scenario(s) must be set in order for DELTA to operate.

Comparing Scenarios

The user may define scenarios by specifying different inputs (e.g., population or economic growth rates). DELTA will project the local effect(s) resulting from the chosen inputs for a particular scenario.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

The model developer encourages users to load outputs from DELTA into their preferred spreadsheets and/or mapping software for analysis.

NEXT STEPS FOR MODEL DEVELOPMENT

The model developer plans to improve the interactions between the urban and regional levels of the model. In addition, the developer would like to facilitate the interfacing of the DELTA system with other models, including different transport models and models for specific processes.

DRAM/EMPAL
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

DRAM/EMPAL may be customized to meet user needs but should cover areas with a population of at least 200,000 persons. The smallest metropolitan area modeled with DRAM/EMPAL was Colorado Springs (pop. 312,000), though during the models' development the area of Hazelton, PA (pop 90,000) was modeled, while the largest was Los Angeles (pop. 6,132,000). The spatial scale is based on census tracks.

Temporal Resolution and Extent

DRAM/EMPAL's temporal extent has been extended 40 years into the future. Forecasts are done in 5-year increments with output from one forecast year becoming the input for the next.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The employment allocation sub-model, EMPAL, forecasts the location of future employment by economic sector to spatially contiguous zones overlaying the metropolitan area. EMPAL does this by taking into account some of the following variables: zone-specific employment levels (total and by economic sector) for a specified time; number of households (population) in each zone, by income level, for a specified time; regional level of target year employment (growth trends); travel time between zones, or other zone-specific measures of accessibility to the work force; and total land area of each zone. EMPAL uses all of this information to estimate the likelihood of a site for future employment primarily based on how often it was selected in the past given the distribution of households and ease of getting to the zone from other zones.

DRAM forecasts the future location of households given this distribution of employment and the attractiveness (including accessibility) of the zones. To do this, DRAM considers the following variables: employment, by type, in each zone [from EMPAL]; impedance (travel time and cost) between zones; percent of households, by type, per zone; and various land uses (vacant developable land [acres], developed land [%], residential acres [%]). DRAM also contains trip distribution models and can project home-to-work, home-to-shop, and work-to-shop trips. An additional submodel within DRAM, called LANCON, calculates land consumption in the forecast period using multiple regression to combine base year data with a forecast.

Calibration of these models is performed with a submodel, CALIB, and consists of estimating the historical relationships between employment in each zone and the above-mentioned variables.

Input Pre-Processing Requirements

Data provided by the agency must be converted into standard formats that can be used by the models.

Model Assumptions

The central assumption is that changes in transportation facilities that result in significant changes in relative travel times will, over time, have corresponding impact on the future distribution of employment and residential locations. Another assumption of the model is that activities (employment and households) are complex nonlinear functions of accessibility to other activities.

Estimating Parameters

All of the equation coefficients must be calibrated in order for the model to operate. These parameters can be re-calibrated using options embedded in software for the model. Recalibration takes just a few minutes per activity type by computer time. Significant time, on the order of months to 2 years depending on the size of the network, may be required if researchers are involved in defining the variables and obtaining the data. CALIB is the calibration program that is used to estimate the equation coefficients in both DRAM and EMPAL. In addition to maximum likelihood estimates of the equation coefficients, CALIB provides goodness-of-fit statistics, asymptotic t-tests of the statistical significance of the coefficients, and point elasticities for sensitivity analysis.

The procedure used for estimation of the parameters is a gradient search procedure. This automatic calibration program is an innovative feature that makes the modeling system unique among its rivals and is one of the prominent features of the model system. Many land-use modeling efforts with other models could not be applied because the model system could not be calibrated properly. CALIB produces estimates of parameters in a systematic way, making it possible to compare values with those of similar regions as an additional degree of comfort for modeling and policy analysis. Furthermore, DRAM/EMPAL provides a quantitative measure of the goodness of fit.

Comparing Scenarios

DRAM/EMPAL addresses multiple scenarios, such as the application of a wide range of transportation demand management (TDM) strategies to different forms of polynucleated urban development. Additionally, land-use controls and scenarios on growth rates and military base closures have been developed.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-processing Requirements

No output post-processing requirements were identified.

NEXT STEPS FOR MODEL DEVELOPMENT

The DRAM/EMPAL models have recently been extended into a new system called METROPILUS. This is an evolution of the DRAM/EMPAL package. According to the developer, it combines employment and residence location and land consumption in a single comprehensive package embedded in a GIS environment.

The model uses a location surplus notion to arrive at the DRAM formulation. METROPILUS increases its reliability through the addition of a lagged variable of households in DRAM. “Land value” in the attractiveness measure of DRAM has also been added. This proposed “land value” is relative house prices in the form of a multi-variate house index giving consideration to single- and multi-family structures.

Implementation is available in phases. First, a data platform is selected to facilitate model component relationships and access to a common database. ArcView is the GIS-based data structure that current DRAM/EMPAL-CALIB uses to interact between model system components, as well as to access mapping and statistical routines. This ArcView-based DRAM/EMPAL package will be an intermediate product. METROPILUS uses this data structure and will eventually contain a reformulation of DRAM and EMPAL with the location surplus notion as mentioned above. This will allow enhancement to component models without sacrificing unaffected routines and submodels.

Growth Simulation Model (GSM)
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

Because of GSM's flexibility, no land is too small or too large to be analyzed using GSM. The dominant constraints are data availability and the financial and staff resources of the entity conducting the analysis. For smaller areas, a greater level of spatial resolution and landuse change algorithms can be incorporated, depending on data availability. For larger areas, a coarser analysis based on limited data is preferable, due to likely constraints on computer resources and the type of data available.

Temporal Resolution and Extent

GSM has no limits on temporal resolution and extent. The dominant constraint is data availability. GSM is currently run based on the target year for which population and employment figures are available, typically 10 to 30 years.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The GSM inventories the supply of develop-able land by measuring the capacity of each area to accommodate new development activity. This is accomplished using geographic information system (GIS) data on landscape features, linked to a variety of geo-referenced data on local land use plans and management programs.

In summary, undeveloped land and land developed below capacity represent the "supply" of developable land in each watershed. Zoning, subdivision, and other regulations and programs affecting development and / or preservation of land are used to estimate the capacities of different types of developable land for new development (e.g., the number of new households that could be accommodated on each type of land under existing or hypothetical programs). A variety of land attributes associated with each develop-able parcel (e.g., distance from or proximity to interstate highways, schools, retail services, and undeveloped land) are used to rate the probability of conversion.

Demand for new development within each small area is distributed by the model to types of developable land based on probability of conversion, capacity, and/or county-specific information on recent development patterns and trends which reflect the market for land in the area. Land use / land cover associated with hypothetically developed parcels is then:

- Converted to a specific type of development to accommodate projected growth;
- Maintained in or converted to forested or other vegetated cover to meet requirements of forest conservation programs, stream buffer protection ordinances, or open space preservation programs; or

- Allowed to remain in its existing condition. This occurs when there is not enough demand for new development to utilize existing capacity.

The model produces an inventory of future land use resulting from the changes.

Input Pre-Processing Requirements

GSM currently receives input as ArcInfo maps, associated ArcInfo attribute data, and relational databases. GSM could be modified to accept data in any relational database that could be tied to ArcInfo. Data inputs must be georeferenced and associated with geographic areas or relational database linkages.

Model Assumptions

Not specified.

Setting Parameters

The amount of effort required to set parameters in GSM is dependent on how the model is being used. GSM currently requires staff with experience in ArcInfo and relational databases to set parameters.

Comparing Scenarios

Multiple scenarios can be compared by running multiple simulations, varying the input data and parameters. The statistical, graphical, and mapped output can then be compared.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-processing Requirements

Output results are currently converted to statistics, graphs, and maps. This requires staff knowledgeable in ArcInfo, relational databases, and graphics packages. GSM is flexible, and can be modified to meet the output needs of the user.

NEXT STEPS FOR MODEL DEVELOPMENT

The model was developed to examine and address land use and growth patterns for the state of Maryland. The model is currently being adapted to run in conjunction with transportation models.

INDEX ®
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The spatial resolution and extent of INDEX® is user defined; it can be a neighborhood, community, or region depending on the extent of the local GIS. The model is suited to evaluate small or large areas – the smallest scale is usually parcels or building footprints.

Temporal Resolution and Extent

The temporal extent of INDEX® is user defined depending on availability of exogenous historic and/or projected data. The model runs scenarios on yearly time intervals.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

INDEX® uses an exogenous population forecast and user-selected policy constraints and incentives to determine where growth should occur in the community. The results of this analysis are scored using a set of environmental performance indicators.

Model Assumptions

None.

Input Pre-Processing Requirements

None.

Setting Parameters

Determined at the time of each community customization. Typical examples include rates of water consumption and solid waste generation by dwelling type; and air pollutant and greenhouse gas emission coefficients according to local generation resource mix and building type. As a sketch-level planning tool, the model is not intended to be precisely calibrated prior to running. Its customization usually includes the ability to set and vary a few basic local parameters, e.g., persons per household by dwelling type.

Comparing Scenarios

INDEX® addresses multiple scenarios such as user-selected alternative land-use plans and urban designs created exogenously.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

Each new community version usually incorporates enhanced functionalities.

IRPUD
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The IRPUD model can examine location and mobility decisions in a metropolitan area on a local level and on a regional level. It subdivides the study area into zones that are connected with each other by transportation networks (e.g., public transportation lines and roads). The present implementation of the model works with only 30 zones. However, the ongoing revision of the model will have some 300 zones.

Temporal Resolution and Extent

A simulation period for the IRPUD model is one or more years. The IRPUD model can be run for any historical period for which data are available. The model can be run as far into the future as the user requires. The accuracy of large-range projections depends on the reliability of the assumptions by the user about socio-economic conditions and transport infrastructure scenarios.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The IRPUD models four major groups of stock variables: population, employment, residential buildings (housing) and non-residential buildings (industrial and commercial workplaces and public facilities). The actors representing these stocks are individuals or households, workers, housing investors and firms. These actors interact on five submarkets of urban development. The five submarkets treated in the model and the market transactions occurring on them are provided below:

- Labor market: new jobs and redundancies;
- Non-residential building market: new firms and firm relocations;
- Housing market: immigration, out-migration, new households and moves;
- Land and construction market: changes of land use through new construction, modernization or demolition; and
- Transport market: trips.

On each submarket, supply and demand interact and result in market transactions. Choice in the submarkets is constrained by supply (e.g., jobs, vacant housing, vacant land, vacant industrial or commercial floor space) and guided by attractiveness, which in general terms is an actor-specific aggregate of neighborhood quality, accessibility and price.

The user must obtain the following data for use as inputs to the model: forecasts of regional employment and population subject to long-term economic and demographic trends; or policies in the fields of industrial development, housing, public facilities and transport.

To implement the IRPUD model, the user must follow four basic steps:

- Data acquisition from various sources;
- Model calibration;
- Model validation; and
- Policy testing.

The user can spatially and graphically analyze the output of the model both during the simulation and offline using custom-written presentation software.

Input Pre-Processing Requirements

All inputs must be in model-specific, fixed format ASCII files. However, utility programs exist to convert input data from other software formats, such as spreadsheet (e.g., Excel) and GIS (e.g., ArcInfo) to model input formats.

Model Assumptions

The IRPUD model makes several assumptions within each of the six submodels: transport, ageing, public programs, private construction, labor market, and housing market.

Transport

Several assumptions go into the equations used in this submodel, including the following assumptions about car availability:

- Car ownership is a function of household travel budgets and other transport expenditures;

- All cars owned by a household are available for work trips;

- Cars not used for work trips are available for shopping and service/social trips; and

- Cars not used for other trips are available for school trips by students with a driving licence.

Ageing

This submodel of the IRPUD model simulates changes of zonal stock variables (i.e., population, employment, residential buildings, and non-residential buildings) which are assumed to result from biological, technological or long-term socio-economic trends or originating outside of the model (i.e., which are not treated as decision-based). Assumptions used in this submodel include:

- Development of birth and death rates, household formation rates, etc.;
- Development of total migration into and out of the study region;
- Development of technological parameters, such as housing technology and costs, car technology (e.g., miles per gallon); and
- Development of incomes, household housing and travel budgets, consumer price indices, etc.

Public Programs

This submodel is used to enter user-specified policies in the fields of land use, housing, non-residential buildings, public facilities and transport into the model. The user is responsible for the consistency and plausibility of the policies, however, the model observes consistent rules for the implementation of the policy (e.g., adds parking facilities for residential and non-residential buildings or public facilities).

Private Construction

This submodel models the investment and locational behavior of private developers. For each type of building, or submarket, the model first determines the overall demand for new construction or rehabilitation based on the vacancy rate in that submarket left over from the previous simulation period. Then the model allocates that total demand to suitable vacant land (or to existing building stock in the case of rehabilitation) based on multiattribute measures of attractiveness indicating the profitability of investing at that location. Land prices and prices/ rents for buildings are adjusted in each period in response to vacancy rates in the submarket.

Labor Market

New hirings, redundancies and changes of jobs are modeled as a function of growth and decline of industries in local submarkets (determined partly by overall socio-economic assumptions and partly by location and relocation behavior of firms in the previous simulation period). This submodel assumes that workers looking for jobs consider their residential location when choosing a job.

Housing Market

The Housing Market Submodel simulates intraregional migration decisions of households as search processes in the regional housing market. In this submodel, households are assumed to adapt their aspiration levels for housing to the supply conditions on the market. Transactions in the housing market consist of starter households (i.e., newly formed households), immigrations or out-migration, and moves. Households consider a move if their housing satisfaction (a multiattribute utility comprising their satisfaction with the dwelling, satisfaction with the neighborhood and satisfaction with the price or rent) is significantly lower than available alternatives in the housing market. The housing market is the first submodel implemented as a stochastic Monte-Carlo microsimulation – it is intended to convert other submodels to microsimulation in the future.

Setting Parameters

There are several ways to determine the values of model parameters. Socio-economic and technical parameters are projected based on other studies, available statistics and expert judgment. Behavioral parameters are, as far as possible, calibrated using available behavioral data (e.g., from travel surveys and housing market statistics). Where no sufficiently disaggregate data are available, behavioral parameters are set by stated-preference techniques and expert judgment and validated by comparing the model results with available aggregate information.

Comparing Scenarios

The user may define scenarios by specifying different inputs (e.g., economic growth rates by sector, immigration and out-migration rates, policies in the fields of land use, housing and public facilities, and transport). The IRPUD model will project the local and/or regional effect(s) resulting from the chosen inputs for a particular scenario.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

Graphical output is either on-screen or in WordPerfect WPG format for later post-processing and printing. In addition, custom-written programs are used to extract model results from the model data base for mapping.

NEXT STEPS FOR MODEL DEVELOPMENT

Future development of the IRPUD model will follow three directions:

- The model is used for a case study of the PROPOLIS project of the European Commission, in which a number of urban land-use transport models are used to conduct comparable scenario runs for a number of European cities (see http://www.ltcon.fi/propolis). For this study, the spatial resolution of the IRPUD model will be extended to about 300 zones.

- Also in the context of the PROPOLIS project, the model developer is adding environmental submodels to the IRPUD model that calculate traffic noise and air pollution indicators.

- In a separate strand of development, the IRPUD model is being gradually converted from its present aggregate form into a fully disaggregate form based on Monte-Carlo microsimulation, following the example of the existing Housing Market Submodel. In the course of this conversion also the existing transport model will be converted to activity-based microsimulation similar to, but much less complex than the TRANSIMS traffic microsimulation developed by the Los Alamos National Laboratory for the U.S. Department of Transportation.

Land Transformation Model (LTM)
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

Spatial extent of the LTM can be any definable region; however, because future developments will focus on coupling land use change and hydrogeologic and geochemical processes, precedence is given to watersheds as the spatial extent in LTM applications. Four different resolution classes are used in LTM: parcel (30 m x 30 m); plat (100 m x 100 m); block (300 m x 300 m); and local (1 km x 1 km).

Temporal Resolution and Extent

LTM can provide forecasts for 20 to 50 years into the future, generally at 5- or 10-year intervals. The model can also be used to hindcast into the past in order to couple to environmental impact models.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The LTM utilizes a set of spacial interaction rules, which are organized into an object class hierarchy. The model is coded within a GIS with graphical user interfaces that allow users to change model parameters. Each module of LTM applies user-defined parameters (e.g., identifying and weighting land use features) to base data to derive study-area conditions. The model uses GIS to make spatial calculations between drivers of land use change and cells being considered for land transition. The values resulting from these calculations are converted to relative land transition probabilities. Though each module of LTM performs a specific function, all modules and submodules are not recognized to be mutually exclusive.

- The Policy Framework module organizes the goals for the watershed's stakeholders (e.g., resource managers, and private and corporate landowners). Stakeholder goals may include: control of pollutant inputs, ecological restoration, or habitat preservation.

- The Driving Variables module contains three general categories: Management Authority; Socioeconomic; and Environmental. Management Authority is an important component since federally and state-owned lands need to be excluded from development. Socioeconomic driving variables include population change, economics of land ownership, transportation, agricultural economics and locations of employment. Environmental driving variables of land transformation are abiotic and biotic.

- The Land Transformation module is characterized by change in land use and land cover. Land uses considered at the most general level are: urban, agricultural/pasture, forest, wetlands, open water, barren and non-forested vegetation. Land cover types that are considered include: types of agriculture (row crops versus non-row crops), deciduous and coniferous forests, and non-forested vegetation.

- The Intensity of Use module considers land management practices, resource use and human activities. Intensity of use can be measured as chemical inputs to the land to increase its productivity, chemical inputs as it results from human activities (e.g., salting of roads) and natural resource use.

- The Processes and Distribution module characterizes groundwater and surface water flows, chemical and sediment transport across land and through rivers and streams, geochemical interactions and fluxes.

- The Assessment Endpoints module provides indicators of ecological integrity and economic sustainability and are used to quantify the nature of changes in landscapes.

Input Pre-Processing Requirements

Land-use and features in the watershed are characterized as a grid of cells made using ArcView and the LTM software. To understand the grids, SNNS needs to have a pattern file. To generate a patter file that could be understood by the neural network, a "C" program was written to convert the files.

Model Assumptions

The LTM uses landscape ecology principles to forecast land use change and to describe the influence of land use change on ecosystem integrity and economic sustainability of large regions

Setting Parameters

Calibration of the model requires expertise in land-use modeling and "C" language programming as well as SNNS neural network batch files. Minimally, either per capita use requirements or the number of cells that will transition during each time step need to be set in order for the model to operate. Recalibration of the model can take several days or weeks depending upon the level of precision required.

Comparing Scenarios

Multiple scenarios can be developed and compared. Detailed information regarding the development of multiple scenarios was unavailable at the time of document publications. One possibility is recalibration of the model; these protocols have not been developed yet.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-processing Requirements

The expertise of an experienced modeler is needed to process the outputs since considerable amounts of variable sensitivity analysis are required to understand the spatial scale of interactions.

NEXT STEPS FOR MODEL DEVELOPMENT

The pilot LTM was developed for the Saginaw Bay Watershed and incorporated two of the six conceptual modules. Future versions of the model will, eventually, incorporate all six modules. Currently, the LTM is being used to provide a preliminary assessment of the impact of 12 years of development and land-use change in the Grand Traverse Bay, MI watershed. Additionally, a model based on the LTM is being developed to examine the changes in land cover patterns as a function of socioeconomic changes, dispersed development, and subsequent changes in the spatial patterns of land ownership in the forested regions of Michigan, Minnesota, and Wisconsin.

Land-Use Change Analysis System (LUCAS) Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The spatial resolution and extent analyzed by LUCAS is defined by the scale of maps used for input. A single grid cell, or pixel, may be defined to a resolution of 90m x 90m.

Temporal Resolution and Extent

LUCAS can provide forecasts for up to 100 years into the future at 5-year intervals.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

LUCAS is a spatially explicit modular system consisting of three modules linked by a common database of driving variables. The first module contains the socioeconomic models that are used to derive the transition probabilities associated with changes in land cover. These probabilities are computed as a function of socioeconomic driving variables including: transportation networks; slope and elevation; ownership; land cover; and population density. The second module contains the landscape-change model and receives as its input the transition matrix produced in module 1 (the socioeconomic models) and accesses the same spatial database of driving variables. A single iteration of the landscape-change model produces a map of land cover that reflects socioeconomic motivations behind human land-use decision making. The third module of LUCAS contains the impact models. These models utilize the land-cover maps produced by the landscape-change module to estimate the impacts to selected environmental and resource-supply variables. Environmental variables include the amount and spatial arrangement of habitat for selected species and changes in water quality caused by human use. LUCAS was developed with the potential for additional ecological impact or socioeconomic modules to be added at a later date.

Input Pre-Processing Requirements

All of the inputs maps must be raster files: discrete grids, or matrices, of numeric values, corresponding to a square parcel of land called a grid cell (pixel). Maps can be stored in an uncompressed (32-bit) format for each pixel or in the run-length encoding format. Each pixel in each map is assigned to one of the data categories for each land use type. For example, categories for vegetation data type could include: forest; unvegetated; or grassy/bushy. Maps for a specific geographic region are compiled into a mapset. The resolution, or pixel size, for each map within a mapset must be the same.

Model Assumptions

LUCAS assumes that landscape properties such as fragmentation, connectivity, spatial dynamics, and the degree of dominance of habitat types, are influenced by market processes, human institutions, landowner knowledge, and ecological processes. The concept of transition, or change, usually in land cover, from a given state to a new state, is central to the model. Transition probabilities are derived empirically through a time series analysis of changes in land cover, while considering road networks, population density, and physical attributes of the land landscape.

Setting Parameters

Calibration of the model requires expertise in land-use modeling and "C++" language programming.

Comparing Scenarios

Multiple scenarios can be compared by running multiple simulations varying the land-cover dependent variable. The graphical and statistical outputs generated from each simulation can then be compared.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-processing Requirements

There are two types of outputs generated by LUCAS: statistical and graphical. The GRASS map layers produced can be stored and re-analyzed in an iterative fashion. To use and understand the statistical outputs, experience in land-use modeling and spreadsheet analysis is necessary.

NEXT STEPS FOR MODEL DEVELOPMENT

LUCAS has been developed and implemented in the Little Tennessee River Basin and the Olympic Peninsula. For additional information regarding further development of LUCAS, refer to www.cs.utk.edu/~lucas.

Markov Model of Residential Vacancy Transfer
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

Spatial resolution: 1 (or more) household(s).

Spatial extent: This model defines change in terms of movement between residential land-use sectors that need not have a specific spatial extent.

Temporal Resolution and Extent

Usually 3 to 5 years; limited by Census data (U.S. Bureau of the Census).

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The Markov chain model measures residential land-use changes in terms of the emergence or disappearance of vacancies within various housing sectors (e.g., high-density rental apartments, detached single-family dwellings, etc.). To do so, users must use linear algebra or data analysis software of their choice to develop a matrix that characterizes the rate at which vacancies by households in one sector (e.g., empty nesters moving out of their single family home) result in vacancies in another sector (e.g., young family moving out of their apartment and into the empty nesters' former abode). As residences are added or removed from the housing market, one vacancy emerges when another is filled. The model projects how the resulting vacancies cascade through the residential housing market.

Users who are familiar with operations research or Markov chain modeling should be able to use the matrix to examine consequences of housing sector changes on vacancies potentially far removed from the actual site of initial change. Others may need to have a computer scientist with quantitative modeling experience to design a basic user interface or run a numerical simulation to utilize the model.

Input Pre-Processing Requirements

A residential vacancy change matrix must be derived from the number of households changing housing sectors over time. This highly mathematical procedure is described in detail in Emmi and Magnusson (1994), as well as by other authors. The procedure could be automated by a programmer who is experienced in linear algebra, differential equations, and related stochastic methods.

Model Assumptions

The model assumes that the urban housing market can be delineated from its "rural hinterland." Internally homogenous housing sectors also are required, although the developers have relaxed this assumption. The model also assumes that the number of vacancies created and transferred into a sector are equivalent to the number transferred from and absorbed out of that sector, and that the transfer probabilities are constant (stationary). The model is also dependent on the assumptions of all Markov models:

- Markovicity: The current state of the system depends on the immediately previous state, and none earlier.

- Stationarity: transition probabilities don't change over time.

- Homogeneity: all state changes within a given sector are subject to a statistically identical set of transition probabilities.

Setting Parameters

The following parameters must be set or calibrated in order for the model to operate:

- Sectoral categories
- Vacancy transition probabilities from one sector to the next
- Net housing created in each sector over each time step

Comparing Scenarios

The model addresses multiple scenarios as follows: Direct and indirect effects of different distributions of vacancy initiations (i.e., new construction) on households' mobility and housing demands across sectors.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

Efforts are being pursued to integrate this model into the residential mobility component of an integrated land use and transportation planning model. The dual solution to a linear programming interpretation of the Markov model is being used to explore the (shadow) housing price implications of pursuing each of several alternative urban growth scenarios.

MEPLAN
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

MEPLAN may be customized to meet user needs and has been used to represent cities, as well as complete countries. Depending on the scale and purpose of the study, the model zone can vary from a few hundred metres in diameter to an entire country.

Temporal Resolution and Extent

Since MEPLAN is highly customizable to meet user needs, the temporal resolution is user-specified. The output data can be modeled for any year in the past or present as well as run for any time interval; however, 5-year increments are commonly used.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

MEPLAN is a stochastic model that is used to project and evaluate the many impacts that planning decisions will have on land use and transport. To do this, it considers supply and demand in both land use and transport and assumes that land use and transport affect each other at all levels. For example, land-use activities, such as industrial development, retailing, and residential expansion, create demands for industrial land, retail floorspace, and housing. In turn, basic supply and demand theory influences prices for space in each land-use category. It is the pattern of prices that influences where people live and work, which affects transportation needs.

MEPLAN has been implemented as an integrated software package with multiple, functionally distinct models and submodels. All of the input parameters and land-use categories are user defined; MEPLAN uses a framework approach within which the user can set up categories and the characteristics of the relationships between categories to represent whatever is required. This maximizes the generality of the model.

The following basic steps generally are needed to implement MEPLAN:

- Data acquisition from various sources
- Model calibration
- Model validation
- Policy testing.

The output of the model can be spatially and graphically analyzed through MAPINFO network and zone plots.

Input Pre-Processing Requirements

The input pre-processing requirements vary and differ for each run of the model.

Model Assumptions

The developers of MEPLAN did not want to build in any pre-conceived ideas of what the user wants to model and, therefore, did not specify any model assumptions. Working within a broad framework, users may define their own assumptions as they implement the MEPLAN framework.

Setting Parameters

The model parameters can be recalibrated by altering the input files for the model. A significant amount of computing is necessary during the setting up and calibration of MEPLAN.

Comparing Scenarios

MEPLAN can address multiple scenarios, but the scenarios have to be coded separately as individual scenarios. The model provides a very flexible system and scenarios are defined by the user.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

The output of the model can be spatially and graphically analyzed through MapInfo network and zone plots. Documentation indicates that post-processing may sometimes be required. The type of post-processing needed was not specified.

NEXT STEPS FOR MODEL DEVELOPMENT

Planned future enhancements of MEPLAN include analysis of the sources of projection errors. Additionally, topics for further model development are currently being explored.

METROSIM
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The METROSIM model covers an entire metropolitan area including its rural fringes. It can include as many zones as necessary. The NYMTC-LUM version includes 3,500$^+$ zones for the New York/New Jersey metropolitan area. The zones can be as small as data permits. For example, in Chicago applications, quartersections of ½ mile by ½ mile were used. The structure of the model is such that it can be operated with many small zones or fewer large zones.

Temporal Resolution and Extent

The METROSIM model can accommodate any number of time periods, but more than 30 time periods are not recommended. Scenarios are run yearly, or some aggregation of years such as 2 years, 5 years, or decades.

METROSIM can produce a one-shot long run equilibrium forecast for transportation and land use in a metropolitan area, or it can operate in annual increments and produce yearly changes to transportation and land use from the existing situation until convergence to a steady state in achieved.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

Transportation, land use, metropolitan growth inputs are used to produce outputs consistent with economic equilibrium (market forces) subject to inputs, policies and land use restrictions to be specified by planners or the users of the model. Cost-benefit measures are produced if desired.

Input Pre-Processing Requirements

Normally, all preprocessing can be done by Alex Anas &Associates.

Model Assumptions

METROSIM does not incorporate any broad assumptions. Calibration procedure checks for data inconsistencies, such as unavailability of sufficient land, etc.

Setting Parameters

METROSIM is calibrated using Census Tract or Traffic Analysis/Land Use Zone data. The key data sets needed in a comprehensive application are:

(1) The census transportation planning package (urban elements 1, 2 and 3);

(2) Data on the link-node destination of the metropolitan transportation networks by mode of travel; and

(3) Data on real estate parcel characteristics and values (generally available from tax assessors in many metropolitan areas).

When the third data set is not available, METROSIM can still be calibrated, although somewhat more simply, using data sets 1 and 2.

Comparing Scenarios

METROSIM can address multiple scenarios of virtually any variety.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

Normally, post-processing of model outputs by the user is not necessary. It is done by the model. However, it may be required for some special purposes.

NEXT STEPS FOR MODEL DEVELOPMENT

Please contact the model developer, Alex Anas, at (716) 688-5816 or aanas@adelphia.net.

SAM-IM
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

SAM-IM can address a regional level or a "microscopic" level (i.e., less than one acre). A land use polygon is the basic unit of geography used in SAM-IM. It envelops an area of homogeneous land use and density. In its most detailed scale, a land use polygon is a parcel. In a more general application, it is a subdivision.

Temporal Resolution and Extent

SAM-IM forecasts future growth in a community using a user-defined future land use layers for a scenario, as well as active and future developments. It will use this information, as well as other factors defined by the user (e.g., undevelopable lands and redevelopment districts) to perform land use allocations. SAM-IM can be used to create scenarios (i.e., conduct land use allocations) for any historical period for which data are available.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

SAM-IM is primarily a growth model. It estimates growth and adds this estimation to information on existing land uses to create a forecast of future land use. Either growth is computed by comparing the forecast theme (i.e., with existing land use or growth) or is computed by comparing the forecast with a base year DRAM/EMPAL (i.e., transportation model) table.

SAM-IM is implemented as an integrated set of modules, each of which is designed to perform a certain function. The modules are ArcView projects, or .apr files. The bullets provided below explain the function of each of these modules and how they relate to one another.

- The Forecast module allows the user to specify and organize all of the socio-economic forecasts.

- The Existing Land Use, Plan, Known Projects, and Other Lands modules all enable the user to edit various types of land use polygons.

- The Scoring module allows the user to assign scores for vacant and redevelopable lands that reflect the probability that the land will be allocated to a portion of the socio-economic forecast.

- The Execute Forecast module allocates the forecast(s) to the future land use scenario according to the rules developed in the other modules.

- The Traffic Analysis Zone (TAZ) Dataset module produces new Travel Demand Model (TDM) input datasets out of SAM-IM results to tie the land use planning process to the transportation planning process.

Input Pre-Processing Requirements

SAM-IM requires some pre-processing of input data, as follows:

- All input land use information (e.g., existing land uses, planned land uses, active development projects, etc.) must be converted from vector representations (i.e., polygons) to grid representation (i.e., raster cells).

- Active and planned development projects must be inserted into the plan that will supercede what is shown in the general plan and generate a file containing a new "plan" grid.

Model Assumptions

SAM-IM enables users to develop their own set of assumptions about land-use suitability; projected growth demands (future population and employment trends and anticipated development densities); and land use controls. The types of assumptions specific to each module are identified below (Setting Parameters).

Setting Parameters

SAM-IM is "configurable" to the requirements of the local area, including land use coding practices, forecast variables of interest, etc. SAM-IM automatically configures itself according to project definitions provided in "configuration" files, which are prepared by the model developer or the user.

The following parameters within each module of SAM-IM must be set or calibrated to operate the model.

- Forecast Module
  - Land use types
  - Socioeconomic sectors (e.g., industrial employment, military, work at home, office employment, etc.)
  - Dwelling unit densities for each land use type
  - Employment densities for each land use type

- Existing Land Use Module
  - Existing land use information (i.e., a base land use condition)
  - A previous scenario developed by SAM-IM that the user would like to select as the base condition for generating a new scenario (i.e., land use forecast)

- Plan Module
  – Future land use layer for the scenario that represents a future vision of urban form and defines how land in the future can be used and at what densities

- Known Projects Module
  – Active developments
  – Planned developments

- Other Lands Module
  – Polygons that establish other “themes” for use in allocating land uses in a scenario, such as undevelopable lands or redevelopment districts. They represent areas where development will be prohibited from occurring based on whatever reasons the user has in mind that are not otherwise reflected in the land use covers themselves.

- Scoring Module
  – Tools for generating GIS layers that reflect site potential based on the user’s standpoint -- and the availability of source data (e.g., flood plain information, buffered highways, proximity to infrastructure, distance from urban lands, total market size within distances of land etc.)
  – Tools for creating, saving, and computing grids
  – Tools for computing logit “choice” equations that reflect the probability that land will be developed

- TAZ Dataset Module
  – Grid cell size
  – Forecast year to be developed
  – TAZ and Land Use Sources
  – Equations to use during the calculation of the trip generation variables

Comparing Scenarios

SAM-IM provides users with the ability to create project scenarios. A project scenario can represent a new urban form alternative, or it can possibly represent different forecasting years (e.g., 2000, 2005, 2010, 2020, etc.). The user interface for SAM-IM is organized around the creation, modification and simulation of project scenarios.

The user may define scenarios by changing the information contained in each of the modules contained in SAM-IM, such as existing land use, future land use, planned and active developments, evaluation criteria, and regional forecasts.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

SAM-IM contains substantial capabilities for producing data sets for use by other urban modeling systems, for example transportation models run by EMME/2. Land use allocations produced by SAM-IM can be summarized for any unit of geography, whether it be traffic analysis zones (such as used by transportation models), municipal boundaries, census tracts – any statistical zone system that can be represented by polygon features. Further, SAM-IM projections can be combined with other socioeconomic data represented by other geographic features to produce data sets needed by other modeling systems. SAM-IM will format these data sets according to the requirements of these other models, offering a range of output format choices including ones that are completely user defined.

NEXT STEPS FOR MODEL DEVELOPMENT

A substantial enhancement program is planned for the next year. Among new features and capabilities will be:

- Faster and more automated procedures
- Modeling scripts to redirect model procedures
- A sophisticated change in the data model to support mixed use developments
- Reallocation mechanisms for addressing allocation residuals
- Probabilistic allocations consistent with logit model formulations
- Development velocity curves to support known development projects already underway
- Simplifications to the "geographic calculator"
- Variable geographic resolutions to provide greater detail in downtown areas and less detail in outlying areas
- Improved accessibility capabilities, including the capability for producing network travel time matrices
- Direct support for DRAM/EMPAL

SLEUTH
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The spatial scale and extent of the SLEUTH model are user defined and, therefore, are variable. Pixel sizes have ranged from 50 m to 1 km. Currently, national (48 contiguous states) and local (Santa Barbara coast) data sets are being calibrated by the model.

Temporal Resolution and Extent

The SLEUTH model, using yearly intervals, can operate as far into the past or future as available historical data will allow.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The SLEUTH model allows users to see how urban areas grow over time by projecting urban expansion. The model is a C program running under UNIX that uses the standard compiler (cc). It contains a land cover deltatron model (LCD) that allows the user to conduct land cover modeling. Users can customize the SLEUTH model for use with their own data sets. After performing a three-phase calibration process, which allows the user to derive the best parameters for historical modeling, the user runs the model to obtain projective information on urban growth. The outputs provided by the SLEUTH model includes animations that illustrate how urban areas grow over time and the impacts associated with growth.

This work is sponsored by the United States Geological Survey EROS Data Center and by the National Science Foundation under the Urban Research Initiative. The SLEUTH model has successfully projected urban expansion for communities on a regional level, including the San Francisco Bay area and the Washington-Baltimore area. In the near future, the SLEUTH model will project urbanization in other major metropolitan areas, such as Portland-Vancouver, Chicago-Milwaukee, Philadelphia-Wilmington, and the New York metropolitan area.

Input Pre-Processing Requirements

Data layers must be on the same projection, same resolution, and map extent. All must be 8-bit GIF files, with values set as data (not in the color table).

Model Assumptions

Assumes zoning and other policy-making does not alter overall coverage of urban growth. Only “planning” factor is where roads are placed. The SLEUTH model can incorporate some zoning alternatives using the excluded layer. The main assumption of the model is that the future can be projected by the past, assuming historic growth trends continue.

Setting Parameters

The automated calibration routines set initial parameters by calibrating the model from historical data.

Five growth parameters must be set, -3 coefficients: 1) dispersiveness of growth, 2) growth at new settlements (breeding), 3) outward expansion plus factors for, 4) the likelihood of settlement up steep slopes, and 5) promoting new settlements near roads or transportation networks. There are 10 additional system and “self-modification” (momentum) constants which also must be set.

Comparing Scenarios

The SLEUTH model addresses multiple scenarios such as the default level of initial urbanized areas, impacts of roads, and other growth factors.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

The SLEUTH model’s scale is being increased towards national and global coverage. Multiple land use types are being introduced into the related “Deltatron” model. Predictive future horizon is being extended as well.

Smart Growth INDEX®
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The size of the area evaluated by Smart Growth INDEX® is user defined; the user selects a land-use cell ranging between 5 and 100 acres. Therefore, the model is suited to evaluate small or large areas (e.g., community or region).

Temporal Resolution and Extent

Smart Growth INDEX® can operate in two different modes: it can provide grid-based forecasts over time (yearly intervals up to 20 years) or it can provide a snapshot of a parcel at single point in time.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

When operated in the “forecast” mode, Smart Growth INDEX® uses an exogenous population forecast and user-selected policy constraints and incentives to determine where growth should occur in the community. The results of this analysis are scored using a set of environmental performance indicators. When operated in the “snapshot” mode, the model scores an exogenous land-use plan or urban design using a similar set of environmental performance indicators.

Model Assumptions

Smart Growth INDEX® assumes that population and employment growth are directly related to a locale’s accessibility to transportation and infrastructure services.

Input Pre-Processing Requirements

The following pre-processing of input data is required:

- All GIS inputs must be in ESRI shapefile format and must be provided at the smallest available polygon levels. All coverages must have a common projection.

- Map units must be in feet.

- In cases in which multiple jurisdictions in a single region have multiple land-use classification systems, they must be converted into a single land-use classification before being imported into the model.

Setting Parameters

The following parameters must be set or calibrated in order for the model to operate:

- Estimated resident, household, and employment growth for each interval year to a maximum horizon of 20 years; commuteshed population; availability of rail transit; study area urban character (CBD, urban, suburban, exurban); existing peak-hour and off-peak levels of service on study area freeways and arterial; allowable number of lanes by functional class; allowable densities of each land-use class; ratios of nonresidential floor area to number of employees; ratios of residential to nonresidential uses in mixed-use land-use classes; percent of infilling to be allowed on vacant lands; transportation fuel consumption rates; building energy demand rates; transportation and building air pollutant and greenhouse gas emission rates; and residential water consumption rates.

Comparing Scenarios

Smart Growth INDEX® addresses multiple scenarios by altering the parameters listed above and modifying user-defined policy constraints and incentives that determine land availability for development.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

The ability to link to additional four-step travel demand models is in development.

Smart Places
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

Smart Places is scalable and can be customized to meet study area needs of end user. Smart Places allows the user to define the scope of the scenario to be considered for evaluation. For example, the user can evaluate the entire design or interactively select land-use categories, regions, or other boundaries within the design.

The spatial resolution of the model is based on the resolution of data provided by the end user.

Temporal Resolution and Extent

Smart Places does not include a temporal component.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

Smart Places looks at input to output relationships in “feature casts” each related to one or more issues of interest. There are no bounds on either the feature or it’s related linked indicator definitions.

An example feature cast for solid waste is given below. Each feature like solid waste is described by one or more indicators. Each indicator may be evaluated using one or more measures. Each measure results in one or more linked indicators. Thus, the definition of each set of feature relationships is given by its feature cast.

Example: Solid Waste Feature Cast

Solid Waste Indicators:
- Residential
- Commercial
- Industrial
- Mixed Use
- Public
- Parks-Recreation
- Utility
- Transportation
- Communications

Solid Waste Information Stock:
- Number of Structures by Type
- Pounds of Solid Waste
- Persons
- Standard Industrial Classification
- Land Area
- Persons/Household
- Pounds Solid Waste/Process
- Pounds Emissions/Ton of Solid Waste

Solid Waste Link Indicators:
- Combined Landuse
- Combined Energy
- Combined Emissions
- Combined Water
- Combined Wastewater
- Combined Solid Waste

Solid Waste Measures:
- Generation Rate/Landuse Type
- Generation Rate/SIC
- Generation Rate/Capita
- Landfill Tons
- Incineration Tons
- Compost Tons
- Recycle Tons
- Reuse Tons
- Landfill Acres
- Vehicle Miles/Ton
- Vehicle Fuel/Mile

Input Pre-Processing Requirements

Certain data may require reformatting to accommodate the GIS.

Model Assumptions

Smart Places enables users to build their own set of assumptions about land use suitability, land use controls, etc.

Setting Parameters

Smart Places requires the user to set various input parameters (i.e., attributes) to evaluate alternative scenarios based on their goals and objectives. Required attributes will depend on the evaluation models defined by the user and may include characteristics such as the number of dwellings per acre, number of persons per unit, and kilowatt hours of electricity per unit per month.

Comparing Scenarios

Smart Places allows the user to address multiple scenarios by changing various assumptions and saving the results of alternative scenarios for comparison.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

A partnership is being formed with Public Technology, Inc. to bring the model to cities in the USA.

TRANUS
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent

The TRANUS model can be used for urban, regional, national or even international applications.

The model is zone-based. Any number of zones may be defined at any degree of resolution. For a metropolitan application the model is typically applied for disaggregations of Regional Planning Districts, ranging from 60 to 250 zones. Model results may be further disaggregated using a GIS-based procedure.

Even if the modeling system does not impose restrictions on the number of zones, there are some obvious practical limitations. In the USA, very detailed data is available for population and land use, but data on employment is less reliable at a finer scale and data on land rents is usually coarse. The purpose of the study is also relevant in defining the spatial resolution of the model. If the purpose of the study is to make strategic long-term projections, then a relatively small number of zones may be sufficient. For short and medium-term projections looking into a specific project in detail (e.g., a mass transit system), a finer degree of resolution may be necessary. The amount of resources available for the study is also relevant. A quick strategic exercise suggests a small number of zones, while a bigger and longer effort probably calls for a large number of zones. Too many zones may become a nuisance, making it difficult to check the results of the model and see any possible errors or inconsistencies.

Temporal Resolution and Extent

The temporal extent of the model is freely defined by the planner, there are no limitations. There have been applications that consider 10 years into the past and up to 40 years into the future. Others have focused on short-term projections such as 5 years into the future.

The time intervals for which scenarios are run are also freely defined by the planner, there are no limitations. Five-year steps are the most common in past applications, with two and three for short-term projections.

TRANUS deals with the temporal scale with a sophisticated ‘scenario-tree’ structure. Each data item in the database has a unique time-scenario reference. After a base year scenario has been defined, the first future scenario is connected to the previous one as a branch of a tree and inherits all the data from it. There is no need to repeat or redefine information; only the changes in each period-scenario have to be introduced. The same is true for subsequent periods, which will be connected to the previous scenario in the tree. This arrangement is very convenient when a project has many scenarios and time periods to deal with, minimizing the possibility of errors.

The scenario tree appears graphically in the user interface database. This structure is clear and economic in terms of computer resources, because each scenario only has small amount of data, since only the changes in relation to the previous scenario in the tree are stored. Any number of periods, scenarios and branches may be defined.

The scenario tree appears in all windows of the interface. The model user may 'navigate' between periods and scenarios to check for changes in the data, which are highlighted with color codes. Data may be copied from one scenario to another. This may be done for a single data item, for sets of data (e.g., all transit routes changes) or to a whole scenario. A network view is available to show what elements have changed for a specific scenario.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description

The TRANUS User Interface automatically generates all files needed by the model programs to run, avoiding the annoying manual elaboration of input files with fixed formats and consequent human errors. The database is object-oriented, which means that each data item is related to all others in logical ways, guaranteeing consistency and minimizing the possibility of errors. TUS also includes facilities for importing and exporting network data, a data validation procedure and an unlimited 'undo' feature.

With the TRANUS User Interface (TUS) it is very easy to set a project for any person familiarized with the Windows environment. Three menus: Project, Land Use and Transport provide commands to create and edit the related entities. Each command opens an Edit Dialog with a field for every data needed. A red color in a field indicates erroneous, inconsistent or missing data. Additionally, a Validate command performs an overall validation of the database, presenting a report of errors and direct access to correct them. TUS provides a context sensitive help for all commands. Copy-and-paste facilities are provided to enable interaction with spreadsheets. Link_Id and Zone_Id codes are provided to facilitate interactions with GIS systems.

Once the project has been defined in the database and the data for one scenario is complete, input files are automatically generated and the user can run the model programs in a very simple sequence. TUS presents assignment results numerically and graphically. A set of complementary programs are provided to produce detailed reports in a variety of formats; the reports may be opened by spreadsheets, where they can be organized at will, adding graphics and prints.

Input Pre-Processing Requirements

The only pre-processing required, depending on the type of input, is arranging the fields in the appropriate order in a worksheet and saving the file as comma delimited text.

Model Assumptions

There are no built-in assumptions about growth or possible changes of the variables into the future. There are many ways in which growth may be specified for any variable in the system. A distinction is made between exogenous and induced production. In urban and metropolitan applications it is common to define some economic sectors, such as agriculture, manufacturing and government, as exogenous to the model. For projections, the growth of these sectors may be given by zone; alternatively, a study-wide growth may be specified (positive or negative), together with a distribution function. A variety of function forms may be specified, such as linear, power or logit, with associated independent variables and parameters. Growth specified through functions may be combined with zone-specific values.

In the case of endogenous variables, such as tertiary employment, households or land types, the model uses the standard allocation procedure based on logit probabilities. The model user may specify attractor functions to influence the location process in various ways, including environmental quality indicators, neighborhood quality, crime rates, slope, floodplains and many others.

For projections the model uses time-periods (cross-sectional) with an explicit dynamic scheme as shown in the figure below. The projection period is divided into time periods t_1, t_2, t_3,… with intervals of, say, 5 years. Changes in the location and interaction between activities automatically generate changes in the demand for transport at the same time period. Any changes in the transport system, such as new roads or improvements in the transit system, also generate changes in demand for the same period. These are short-term dynamics. Changes in the transport system imply changes in accessibility patterns that affect or feedback into the activities and land use system. In this case the model assumes that such changes take time to consolidate, as residents and firms change their travel patterns. For this reason, changes in accessibility affect the land use system for the next time period t_{i+1}.

Finally, the horizontal arrows that link the activity system from one period to the next represent elements of inertia. The model user defines which elements of the land use system affect or restrict changes occurring in the next period. The model user also defines the time steps.

Setting Parameters
All the equation coefficients and parameters must be set or calibrated in order for the model to operate.

Comparing Scenarios
The TRANUS model system provides a large number of indicators to support the comparative analysis of alternative scenarios. A special program is specifically designed to compare two sets of transport results corresponding to two alternative scenarios; the program estimates the consumers' surplus derived from the application of policies.

The range of policies and projects that may be compared and analyzed is very wide. These may be broadly classified as land use policies, transport policies, and combined land use-transport policies. Any number of projects and policies may be combined to form a scenario. The list of possible policies that can be represented in the TRANUS system is very long. The following is in no way exhaustive but serves as an indication.

- Urban development plans, smart growth initiatives, metropolitan plans, etc.
- Land use controls
- Impact of specific projects such as new industries, housing developments, commercial centers, etc.
- Regional development plans
- Housing programs and policies
- Environmental protection programs, constraints to preserve special areas, etc.

- New roads or improvements to existing ones
- Reorganization of the transit system (new routes, tariff structures, integrated fares, etc.)
- Bus-only lanes
- Mass transit systems
- Toll freeways, urban or regional
- HOV lanes programs and facilities
- Demand management programs, car bans or limitations, etc.
- Pricing policies, such as road-pricing, fuel taxes, parking surcharges, etc.
- Park-and-ride
- Selective road-pricing and congestion pricing
- Road upgrading and rehabilitation
- Road maintenance programs and policies
- Railway projects and improvements
- New port facilities, relocation or improvement of existing ones
- New or relocation of freight and passenger airports

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements
None.

NEXT STEPS FOR MODEL DEVELOPMENT

Modelistica has a permanent and continuous research and development program for the TRANUS model. Included in the effort is a to-do list of future developments and new features for the TRANUS model, covering all areas. A new version is released at least once a year, with several sub-versions approximately once a month. As of May 2000, the most recent version is January 2000.

UGrow
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent
UGrow's spatial extent is variable depending on the size of area explored. Its spatial scale is also variable depending on available GIS data.

Temporal Resolution and Extent
UGrow's temporal extent is between 1,950 and 2,100, depending strongly on the time frame of interest**,** with yearly scenarios provided.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description
UGrow is a system dynamics suite of models for urban policy design and testing. Numeric (system dynamics), spatial (GIS – maps) and 3-Dimensional (fly through visualization) are tools which are integrated to serve a community's needs. Most jurisdictions prefer a limited numeric model and may substitute population forecasts by housing type (per decade) to serve as an input to the spatial model. The spatial model uses this information to determine how much land must be developed to meet future housing needs. The spatial model then places this development in accordance to "growth rules" selected by the user groups. These rules are essentially the specific zoning a community may apply to generate a variety of growth scenarios and may read: permit growth of single family on 1 acre parcels only within 1 mile of paved roads, and allow multifamily only within 2 miles of town centers, and prevent any development within any designated open space or riparian area, etc. Different factions within a community may use this capability to define growth as each may prefer it and the model will generate maps, by decade, into the future showing these differing scenarios.

The UGrow developers can pull any spatial scenario into the 3D model and fly this "community of the future" showing new development and its relationship to the currently built environment.

Input Pre-Processing Requirements
UGrow requires the setting of all initial conditions, through extensive model focusing and issue generation, before any inputting of data.

Model Assumptions
The UGrow model's assumptions are adaptable to the ones chosen by the user.

Setting Parameters
Confidence is built in the model structure by comparing the UGrow model output against historic data.

Comparing Scenarios
The UGrow model addresses multiple scenarios. The particular scenarios addressed depend on the issues of interest to the user.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements
None.

NEXT STEPS FOR MODEL DEVELOPMENT

UGrow developers are currently developing an “Event Model” which can move across proposed community growth scenarios. The event may be a tornado, drought or storm depending on the attributes assigned and will highlight the risks of development in certain areas. This work is NOAA/DOD funded.

UPLAN
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent
UPLAN can be customized to meet the study area needs of the end user. Once the model has been operated, the information is saved to a file. UPLAN can incorporate previous files with each new run. Therefore, the program theoretically does not have an upper limit, although a consistent land use data set must provide the basis for UPLAN and larger areas may be more complex as multiple jurisdictions and General Plan land use maps are included.

Low-density residential is represented in a 10 acre parcel size (200 m cells), while all other land uses are represented by ½ acre parcel size (50 m cells). The user determines all cell sizes.

UPLAN is appropriate and cost effective for areas that are experiencing or anticipating growth and have a significant amount of open space potentially available for development. The model develops growth in a specific pattern that aligns itself with the roadway system, slopes, services, and general plan designations.

Temporal Resolution and Extent
UPLAN uses 1990, or any year, as its base year and can accommodate different projection periods. The time interval for which scenarios are run is determined by the user.

Temporal scale depends on the UPLAN module being considered. The dates for the growth and allocation modules are user defined.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description
When operated in the “forecast” mode, UPLAN uses an exogenous population forecast and user-selected policy constraints and incentives to determine where growth should occur in the community. The results of this analysis are scored using a set of environmental performance indicators.

Input Pre-Processing Requirements
The following pre-processing is required for the inputs listed in the UPLAN fact sheet:

- Growth projections must be summarized so they can be hand-entered into “UPLAN” to provide a user-specific model
- The community must determine level of compliance with the General Plan
- The community must define future infrastructure plans. Standard GIS overlay functions must be used to create the various “Grids” used to study area
- Community must define existing infrastructure plans

Model Assumptions
The UPLAN system enables users to build their own set of assumptions about land use suitability; projected growth demands (future population and employment trends, assumed household characteristics, and anticipated development densities); and land use controls and infrastructure. The types of assumptions are listed below under "Setting Parameters."

Setting Parameters
UPLAN requires the end user to set various input parameters called "Grids" to evaluate alternative urban growth scenarios. The grids are overlaid with each other to develop a specific scenario. The user does not need to input parameters to operate the model, UPLAN has a set of default parameters that can be used to run the model. The required parameters are listed as follows:

- Attraction Grids (areas development can occur in the future)
  - Freeway Ramps: This grid represents the location of the on/off ramps of a freeway. The logic being these areas are highly desirable locations for development.
  - Minor Highways: This grid represents desirable locations for development since the highway is considered to have multiple access points.
  - Major Arterials: This grid is considered to have full access, therefore, it is considered a desirable location for development.
  - Minor Arterials: This grid is considered to provide intersections with other arterials.
  - Cities and their Spheres of Influence: This grid represents the city and the area where development will likely occur in the future.
  - Light Rail Stations: This grid provides location of existing and future stations and is considered an attraction for development.
  - Industrial Allocation attractions: Airports, Ports, etc.
  - Factor weights: numeric values indicating the relative importance of different factors for determining suitability, with the user setting the number of buffers and their distance from the attractor.

- Exclusion Grids (areas development should not occur)
  - Regional General Plan: This grid is a generalized composite of all general plan land use maps for the user's location.
  - Rivers/Lakes: This grid represents naturally occurring waterways. A user- defined buffer area can be inputted.
  - Floodplains: This grid represents the 100-year floodplain elevation.
  - Slope: This grid provides areas too steep for development and a weighing factor for varying slopes.
  - Public Lands: This grid provides all areas designated as publicly-owned.
  - Fire Severity: This grid provides levels of potential fire severity.
  - Existing Urban: This grid allows user to test redevelopment policies at a detailed scale. It is best if this layer is in a fine grid, such as 25 m cells, so that vacant lands are accurately depicted.
  - Open Space: This grid provides location of "public open spaces" this includes parks, etc.
  - Farmlands: This grid provides agricultural locations.
  - GAP Vertebrate: This grid provides location of important habits. The WHR tables associate animals with the vegetation types.

- Allocating Demographic Land Use
  - Residential: (1) population projection; (2) demographic and land use characterization the user wants to review; (3) persons per household; (4) percent of households in each density class; and (5) average parcel size for each density class.
  - Industrial/Commercial: (1) all the above from residential; (2) workers per household; (3) percent of workers in each employment class; and (4) average floor space per worker and floor area ratio for buildings.

- Existing Urban Land Use
  - User indicates previously developed areas.

Comparing Scenarios
UPLAN offers four modules that enable the user to modify the allocated land use:

(1) Strict Compliance: Requires the model to adhere to the land use designations in the user's General Plan,

(2) Limited Compliance: Allows the model to modify the land use designations in the General Plan to incorporate the previous allocated land use,

(3) Industrial Compliance: Requires all industrial land uses be delegated to industrial land uses, whereas all other land uses can go anywhere, and

(4) No Compliance: Allows the model to delegate all land uses to any other land use.

These four scenarios provide the user with alternatives in determining future land uses. Scenarios can be further defined by developing new road layers or transit layers, to attract development to different locations, and be defining environmental constraints, such as urban growth boundaries or habitat preserves.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements
Data summaries, per user needs.

NEXT STEPS FOR MODEL DEVELOPMENT

The next step is developing a series of urban impact models that will run off of the land use layer (costs from wildfires, costs from flooding, local service costs, habitat damage, agricultural lands losses, surface water quality, threats to groundwater, etc.).

UrbanSim
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent
The UrbanSim model covers the metropolitan region and surrounding area. The coverage area is user defined and can include surrounding watershed areas or other ecological areas.

UrbanSim currently operates at level of a spatial grid of user-defined resolution. Current applications of the model have used 150 meter resolution.

Temporal Resolution and Extent
UrbanSim operates on annual simulation steps, and can be run as far into the future as the user requires, though accuracy clearly diminishes with longer time horizons. Capacity to represent model uncertainty over time is being developed. The annual time steps of the model are not a fixed feature of the model. Time steps could be varied to be longer or shorter.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description
The use of the modeling system consists of three phases. The first phase, data preparation, entails assembling and integrating the necessary data to load the database for the model. The second phase, calibration, entails specifying the model components or using the existing specifications, using tools provided in the model system to generate special data extracts formatted to facilitate use in econometric software such as Limdep, and estimating the coefficients of the model equations using the local database. Further calibration of model coefficients is completed once all the model equations are estimated individually. The third phase of the model use, application, involves the construction of policy scenarios that reflect land use and transportation system plans, pricing and other regulatory policies towards development, such as environmentally sensitive lands, or the use of Urban Growth Boundaries. The model is run on individual scenarios, and the results of each scenario are exported on an annual basis. These results can be visualized using the UrbanView component, or exported to external database and GIS tools for further manipulation and analysis. Further work is planned to develop policy performance indicators that provide summary measures to facilitate comparison of scenarios.

Input Pre-Processing Requirements
UrbanSim requires some pre-processing of input data, as follows:

- Creation of a spatial grid for the study area, at a user-defined resolution
- Integration with environmental and policy constraints, using polygon overlay on the grid
- Integration of parcel data, using polygon overlay to intersect with the grid

- Integration of business establishment data, using point in polygon assignment to link to the grid

- Integration of household travel survey data, using point in polygon assignment to link to the grid

- Processing of census STF3A and Public Use Microdata, to prepare inputs for household synthesis.

Model Assumptions
The model assumes that external policy assumptions (such as a land use plan) will be binding, and that underlying behavioral preferences calibrated in the model are invariant over time and capture the most significant aspects of the relevant behavior of the real estate market demand and supply interactions with travel. Work is being done to introduce a capacity to test the degree to which land use plan policies are binding, based on historical analysis of development and land use plan designations. These effects can be calibrated in the developer model using local data. The model is designed to reflect probable outcomes of policy changes and general trends in metropolitan development. It cannot be expected to predict with tremendous accuracy at the level of the grid cell for two or more decades into the future, and users are likely to generally use and distribute more summary forms of the model predictions. The grid detail provides flexibility in aggregating results using different zonal configurations.

Setting Parameters
The following parameters must be set in order for UrbanSim to operate:

- Land price model coefficients
- Developer model coefficients
- Residential location model coefficients
- Employment location model coefficients
- Mobility rates

Comparing Scenarios
The user interface for the model is organized around the creation, modification, and simulation of policy scenarios. The user may define scenarios combining transportation infrastructure and pricing, land use plans, density constraints, urban growth boundaries, development impact fees, and policies regarding development of environmentally sensitive lands such as wetlands, high slopes, or floodplains.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements
None. The output data can be loaded into external software for further analysis, as needed by the user.

NEXT STEPS FOR MODEL DEVELOPMENT

The principal areas of current and future development of the model system are the following:

- Model components to simulate land cover, water demand and nutrient load.

- Model components to implement activity-based travel modeling within the system.

- Refinements to the UrbanView visualization component.
- Development of a refined user-interface for the model and visualization system.
- Development of Web-access tools for model visualization and potentially for model operation.
- Development of tools to facilitate user-specified evaluation indicators for the model and visualization.
- Development of calibration tools to internalize the capacity to estimate all model parameters.
- Development of a modeling language or building blocks to facilitate development and modification of model components with minimal software coding.
- Development of data mining and robust data cleaning tools to facilitate data integration for the model system.
- Development of approaches to integrating the model system with ongoing monitoring and assessment of planning objectives and short-term planning and capital improvement decisions.
- Development of microsimulation of real estate market interactions, with prices emerging from the interaction of consumers and suppliers.

The UrbanSim project is a long-term research project designed to provide tools to assist in planning sustainable and equitable approaches to metropolitan development. Using an Open-Source approach to software development, the project seeks collaboration with academic researchers and with practitioners in the further development and application of these tools. Those interested in potential collaboration should contact the project team at the University of Washington.

What if?
Additional Technical Information

GEOGRAPHIC AND TEMPORAL SCALE OF MODEL

Spatial Resolution and Extent
What if? may be customized to meet user needs, although it is best suited for sizes larger than a single parcel of land. Because it incorporates user data, the resolution is that of the data provided.

Temporal Resolution and Extent
Since What if? is highly customizable to meet user needs, the temporal resolution is user defined, based on available information and study interests. The model can accommodate up to four different projection periods.

APPROACH TO MODELING INPUTS FOR OUTPUT GENERATION

General Description
Each module of What if? applies user-defined decision criteria (e.g., identifying and weighting land-use suitability factors) to base data (e.g., current land uses) to derive study-area conditions. These decision criteria are applied to land-use information stored in geographic information system (GIS) data bases to create maps and reports showing 1) the relative suitability of different locations for various land uses under alternative development scenarios (suitability analysis maps) and 2) where future development may occur (allocation maps). Each module of What if? performs a specific function:

- The suitability module applies standard "weighting and rating" procedures based on users' inputs for various land-suitability criteria and their relative importance to create maps and summary reports showing the relative suitability of different locations for different land uses.

- The growth module converts the five main categories of land use demand (i.e., residential, industrial, commercial, preservation, and locally oriented uses) into equivalent future land-use demands based on projected growth for the study area. The system user defines projected growth for each land use type (e.g., total number of households, total regional employment by industry and commercial category) and the system calculates the projected demand in each projection year for each land use type. What if? can account for up to four future projection periods.

- The allocation module produces maps and reports indicating where projected growth may occur given user-specified information on land suitability, land-use demand, infrastructure provision, and land-use plans and controls.

Input Pre-Processing Requirements
The following pre-processing of input data is required:

- GIS Inputs: Standard GIS overlay functions must be used to create Uniform Analysis Zones (UAZs) for the study area. UAZs are map layers of information on natural features, infrastructure plans, existing land-use patterns, and approved comprehensive plans or zoning ordinances that are combined to create homogeneous land units. GIS "UNION" commands are used to combine these layers into a single layer made up of UAZs containing information from each of the constituent layers. UAZs are stored as ESRI shapefiles for incorporation into What if?.

- Growth Projections: Growth projections must be prepared so they can be hand entered into What if? as the following: 1) number of residential households per year; 2) percentage of residential households per scenario; 3) housing density for each housing type; 4) average household size for each housing type; 5) residential vacancy rates; 6) proportion of existing housing units that will be lost to demolition, fire, and so on; 7) total regional employment; 8) density of employees per industrial/commercial type; 9) average square footage of floor space per employee; 10) industrial/commercial floor area (FAR); 11) vacancy rates; 12) amount of land that should be preserved – total amount, percent of study area; and 13) acres needed to meet various local demands (e.g., recreational infrastructure) per 1,000 new people.

- Alternative Development Scenarios: The community must define its own suitability, growth, and allocation scenarios.

- Land-Use Classifications: Community must define its desired land-use classifications.

- Infrastructure Plans: Community must define its future infrastructure plans.

Model Assumptions
The What if? system enables users to build their own set of assumptions about land-use suitability; projected growth demands (future population and employment trends, assumed household characteristics, and anticipated development densities); and land-use controls and infrastructure. The types of assumptions specific to each module are identified below (Setting Parameters).

Setting Parameters
The following parameters must be set or calibrated in order for the model to operate:

- Suitability Module
  - Suitability factors such as slopes, soils, 100-year flood plain, flooding potential, endangered species, stream buffers, and other factors that the user has data on and wants to consider. These must be identified for each land use under consideration.
  - Factor weights: numeric values indicating the relative importance of different factors for determining suitability.
  - Factor ratings: numeric values indicating the relative suitability within a particular factor type.
  - Permissible land use conversions: identification of which land uses may be converted from their current use.

- Growth Module
  - Residential: 1) total number of households in the region; 2) the study area's share of regional households; 3) breakdown of housing type for new residential construction; 4) housing density for each housing type; 5) average household size for each housing type; 6) residential vacancy rates; 7) proportion of existing housing units that will be lost to demolition, fire, and so on.

- Industrial/Commercial: 1) total regional employment; 2) density of employees per industry/commercial type; 3) average square footage of floor space per employee; 4) industrial/commercial floor area; 5) vacancy rate.
- Preservation: amount of land that should be preserved in total acres and as percent of study area.
- Local demands: estimates of acreage needed per 1,000 new people for neighborhood retail, public/semipublic areas, parks and recreation, or other locally determined need.

- Allocating Demand Module
  - Allocation priority: order in which projected land-use demands are to be allocated.
  - Infrastructure controls: identification of previously defined infrastructure plans, indication of the type of infrastructure required for each land use type (e.g., user indicates whether it is “not affected,” “required,” or “excluded”).
  - Land-use controls: user can indicate previously defined land-use plans and zoning ordinances.

Comparing Scenarios

The model addresses multiple scenarios as follows: What if? offers three modules that enable the user to: 1) determine the relative suitability of different locations for different land uses and to specify the relative importance of alternative suitability factors and ratings for the different factor types, 2) determine the projected demand for different land uses in each projection year, and 3) allocate the projected demand for each land use to locations on the basis of their suitability for that use and user-specified land use controls and infrastructure expansion plans. Within each of these modules, different scenarios are possible. The scenarios are user defined and used by What If? to determine future land-use patterns.

ADDITIONAL INFORMATION ON MODEL OUTPUTS

Output Post-Processing Requirements

None.

NEXT STEPS FOR MODEL DEVELOPMENT

Planned future enhancements of What if? include: 1) a version that can be operated via the World Wide Web, 2) an interface with traffic demand models, and 3) a fiscal impact module.

Appendix C
Current Trends in Community Growth and Planning

Current Trends in Community Growth and Planning

Lying at the heart of growth-management initiatives is the desire to control the rate of sprawl. Narrowly defined, *sprawl* is the "unplanned, uncontrolled, and uncoordinated single-use development that does not provide for an attractive and functional mix of uses and/or is not functionally related to surrounding land uses..." (National Research Council, 1998). See Exhibit C-1 for some of the characteristics that have been used to define sprawl.

Exhibit C-1. Characteristics Defining Sprawl

- Low-density development
- Development requiring dependence on the automobile
- Segregated land uses (e.g., commercial, industrial, or residential)
- Large distances and poor access between housing, jobs, and schools
- Consumption of land occurring at a faster rate than population growth
- Consumption of agricultural land/or environmentally sensitive land

Source: U.S. General Accounting Office. April 1999. *Community Development: Extent of Federal Influence on "Urban Sprawl" Is Unclear.*

Many communities associate sprawl with traffic congestion, environmental degradation, a loss of heritage landscapes, a deteriorating sense of community, central city and inner suburb decay, and the accompanying isolation of disadvantaged populations. These communities are witnessing the loss of precious landscapes at an alarming pace, are often subject to increased property taxes despite the strong economy, and are spending more and more time on congested roadways.

Communities around the country are trying new planning tools and techniques in an attempt to curtail some of the negative effects of sprawl. Through innovation and the use of land-use change models, they are finding ways to preserve community character, revitalize downtowns, preserve open space, and obtain an improved quality of life. In Maryland, a Smart Growth initiative aimed at restoring downtown economies, a sense of community, and the environment, with a focus on placing funding priorities on infrastructure investment, successfully passed the ballot in 1997. Portland, Oregon, continues to attract national visibility through the successful implementation of its growth boundary and its expansion of Portland's light rail system. In Michigan, a statewide coalition of transportation experts and grassroots activists launched an initiative to develop technically feasible alternatives to congestion. By doing so, they were able to address the loss of farmland and concerns over the increases in traffic congestion. More initiatives like these are occurring across the country.

Successful implementation of the above techniques, however, requires community members and planners to have a better understanding of the links between land use, transportation, housing, and employment location decisions. An understanding of land-use models that bring together these links will help communities determine how to use such models to assess the implications of growth, project the outcomes of different planning choices, and strengthen decision makers' abilities to effectively manage growth in the interest of the community.

1.0 Suburbanization: A Snapshot

While sprawl has become a hot topic over the past few years, suburbanization, as a settlement form, has had a long history in the United States. In the late 1860s, Riverside, Illinois, became a model for suburban development–a model that subsequently has been copied in virtually every major city across the country. Characterized by curving tree-lined streets and expansive lawns, this model still dominates concepts of land subdivision for single-family detached units today.

By the 1920s, with rising affluence and the growth in automobile ownership, middle-income families introduced the first massive residential migration to the suburbs. A second mass migration followed the Great Depression and World War II in the 1940s. Perhaps the most famous suburban housing development of this era was Levittown, New York. Levittown and other similar large suburban developments were made possible by government-backed financing and mortgage insurance programs. The 1956 Interstate Highway Defense Act further facilitated residential and industry relocation outside central cities with the largest public works program ever completed in the United States and 60 billion dollars' worth of investment toward the construction of an initial 40,000 miles of limited-access highways. By the 1950s, most postwar development was occurring in suburban areas; population decline and physical deterioration became some of the problems central cities had to face.

Traditional zoning separating urban land by residential, commercial, industrial, and agricultural uses has, in recent years, been faulted for contributing to unsustainable development patterns and lowering our quality of life through increased reliance on the private automobile and greater traffic congestion. Ironically, traditional land-use zoning, despite its recognized shortfalls today, was first introduced in the 1920s as a means of protecting the health and safety of inhabitants of major cities. During the first decades of the 20th century, urban residents living in dense tenements void of direct sunlight or air were at great risk of fire and illness. Residents of smaller, but growing, cities often found themselves next door to pollution-churning factories. Zoning, through the separation of incompatible uses and specification of the density of those uses and bulk of building on the land, enabled cities such as New York to better protect the health and welfare of its citizens. Today, with our economy based on cleaner high-technology and service industries, there is less need for universal application of traditional zoning laws. Nevertheless, there is a continual push toward the suburban form of development, encouraged in large part by interstate and intrastate highways providing greater accessibility to the outlying areas. Citizens still desire to own homes on quarter-acre lots away from the congested roadways and dense development that are characteristic of urban centers. Unfortunately, along with this desire, come longer commutes and negative impacts on the natural environment.

2.0 Changing Trends

Across the country, sprawl is providing benefits, such as increased home and business ownership due to lower property costs, but it is also taking its toll on environmental and fiscal resources and is putting great strains on our quality of life. The costs of delivering public services to newly developed areas, for instance, is going up rapidly. Not only does sprawl consume open space as it moves outward from a city, but it is doing so at a rate much faster than population growth. For example, in the Philadelphia metropolitan area, population grew by a mere 3.8 percent between 1970 and 1990, while the amount of land in the region used for urban purposes grew by 36 percent (Katz, 1997). On a national scale, between 1950 and 1990, urbanized land expansion grew at three times the rate of population growth (Rusk, 1999).

The American Farmland Trust examined the U.S. Department of Agriculture National Resources Inventory data spanning the decade from 1982 to 1992, and concluded that almost 14 million acres of America's farmland were lost to development, 31 percent of which was prime farmland (Sorenson et al., 1997). In the Washington, D.C., metropolitan area, more than 200,000 acres of farmland, barren land, forests, and wetlands were lost during the building boom decade of the 1980s; this area is nearly five times the size of the District of Columbia (National Center for Resource Innovations, 1997).

Residents in many metropolitan areas rank traffic congestion as one of the most serious local problems. The Texas Transportation Institute estimated that, in the country's 70 largest urban areas, the total cost of traffic congestion amounts to almost $74 billion per year with 88 percent of that cost attributed to delay (Schrank and Lomax, 1998). Annual costs per individual driver are as high as $1,290 in the Washington, D.C., area (Schrank and Lomax, 1998). On a national level, drivers stuck in traffic consumed more than 6 billion gallons of fuel in 1996–enough to fill 670,000 gasoline tank trucks. Drivers from the most congested cities use five times more fuel than those in the least congested cities (Schrank and Lomax, 1998).

While staggering, these numbers are not entirely surprising given that the increase in total vehicle miles traveled was double that of population growth between 1970 and 1996 (Bureau of Transportation Statistics, 1998). This increase in travel, combined with larger vehicles, has largely offset gains made by catalytic converters and improved engine technology. Although mandated by the Clean Air Act, 130 U.S. cities still fail to meet National Ambient Air Quality Standards for ozone, carbon monoxide, sulfur dioxide, or particulate matter pollutants (USDOT/USEPA). Nationwide, 25 percent of all air pollution is the result of vehicular travel (USDOT/FHWA, 1999). Each year, the average car emits over 600 pounds of air pollution (Washington State Department of Ecology, 1997).

Air quality is not the only natural resource concern of communities. Water quality is inversely related to the land area devoted to impervious surfaces (parking lots, rooftops, and roads). As little as 10 percent impervious surface area can lead to degraded streams and rivers in a watershed (American Rivers Association, 1997). The increased flow of runoff and accompanying chemical constituents not only affects aquatic plants and animals, but also hastens erosion, alters the shape of stream beds, and changes the temperature of the stream, taxing the survival of certain aquatic species.

The same forces that have shaped suburbanization have led to disinvestment of our central cities and isolation of our most vulnerable population–the urban poor. As more jobs move out into the suburbs, people who cannot afford cars have difficulty reaching employment areas on transit systems that do not adequately service low-density suburban areas. Public dollars that could otherwise be spent on maintaining central city infrastructure and addressing the needs of urban citizens are absorbed by newly developing areas. Too often, low income and minority populations of these central city communities are further disenfranchised by the siting of hazardous waste incinerators, regional transportation arteries, and other undesirable infrastructure.

Hand-in-hand with these discouraging effects of sprawl and surburbanization are dramatic fiscal impacts. Increasingly, localities are realizing that certain types of growth do not always pay their way. New jobs mean new residents. New residents need new schools, water and sewer lines to connect to their new homes, and new fire and police stations for public safety. The Maine State Planning Office calculated a 60-percent increase in local government spending per household (approximately $1,700) from 1980–81 to 1990–91 that can be attributed to rapid low-density growth. More than $300 million was spent on new school construction in fast-growing areas between 1975 and 1995 despite a drop in student enrollment (PAS, 1999).

3.0 Initiatives

An increasing awareness of the potential costs of sprawl has prompted citizens, planners, and local government officials to reassess where we are and where we want to be. A desire for more sustainable-development patterns and a high quality of life have instigated a number of new initiatives that are addressing sprawl-related problems. These solutions have risen from the local, state, regional, and federal levels of government. Because each initiative is unique to a particular sprawl situation, communities should recognize that their individual planning strategies must be based on their own legal authorities, political environments, and cultures. The state, local, regional, and national initiatives discussed below are a few of the sustainable actions currently being implemented across the country.

3.1 State and Local Initiatives

By structure of the U.S. Constitution, land-use planning and zoning are functions of state and local governments. Thus, significant changes in urban development patterns are highly dependent on local initiatives. The states and local governments deal with the problems attributable to sprawl in different ways, from regional growth boundaries and zoning to fiscal and tax-base measures. The discussion below summarizes two of the more prominent programs: 1) land-use planning and zoning, and 2) adequate public facilities tests.

Land-Use Planning and Zoning

Communities have long attempted to shape development through zoning and other planning tools. The backbone of planning in the United States is the general or comprehensive plan supported by the zoning ordinance. This type of plan provides a long-range view of a community's projected population growth and land use, transportation, housing, utility, and recreational resource and expansion needs. Most plans include a statement of goals and policies that articulate a community's vision for its future. While general in nature, the comprehensive plan should guide a jurisdiction's zoning, subdivision regulation, budget, and capital improvements plans.

Zoning is the predominant land-use control employed by local governments. Local governments track their land resources through an inventory of land area by designated use. One popular land-use classification system adapted by many localities around the country is the Anderson system, in which more general land-use classes, such as urban and nonurban, are further broken down through a hierarchy of increasingly detailed levels (Kaiser et al., 1995). Exhibit C-2 illustrates how the Anderson classification can be adapted for a county or small city.

Exhibit C-2. Adaptation of Anderson Land-Use Classification System for County or Small City

Urban	Residential	Low-density
		Medium density
		High density
	Commercial	Mixed-use (commercial/residential)
		General retail (central business district, shopping center)
		Professional services and office
	Industrial	Light industry/warehousing
		Heavy industry
		Industrial/research park
Nonurban	Agriculture	Cropland
		Orchard
	Forest	Deciduous
		Evergreen

Source: Kaiser et al., 1995

Traditional zoning separates land uses into four primary categories or classifications: residential, commercial, industrial, and agricultural. While it continues to be universally implemented across the country, traditional zoning has in recent years come under scrutiny as a contributor to sprawl. This form of zoning separates homes from places of work, leading to longer commutes and empty downtowns after the evening rush hour. New zoning tools such as planned-unit and transit-oriented development, overlay, and floating zoning are being used to encourage new development patterns, especially mixed-use development with greater flexibility in residential and commercial densities.

Beyond comprehensive planning and zoning, various communities and states have adopted additional tools to manage growth. One such tool is urban growth boundaries. Urban growth boundaries concentrate development inside a mapped boundary line and preserve agricultural land outside. The best-known example of a successful urban growth boundary is Portland, Oregon. In 1973, the state of Oregon passed legislation requiring that all urban areas designate growth boundaries to keep sprawl in check. Between 1980 and 1989, more than 90 percent of Oregon's new residents were located inside Urban Growth Boundaries (Weitz and Moore, 1998). Portland complements its land-use planning with a nationally recognized light rail transit system and encouragement of higher-density mixed-use developments around transit stations. Between 1990 and 1995, annual transit trips per capita increased 4.4 percent during a period when ridership on similar transit systems elsewhere dropped (USDOT, 1997).

Adequate Public Facilities Tests

Some communities have introduced tests of adequate public facilities and focused investment planning as a means of addressing a community's capacity to service additional development. In Montgomery County, Maryland, subdivisions will not be approved unless developers demonstrate that adequate facilities exist to service the proposed development. These facilities include roads and public transportation facilities, sewer and water service, schools, police stations, firehouses, and health clinics. A growth policy report prepared annually guides the County planning board's implementation of the adequate public facilities ordinance. Maryland's recently adopted Smart Growth legislation focuses state investments on county-identified priority funding areas as a means to encourage development where infrastructure is already in place and in locations consistent with the Smart Growth and Neighborhood Conservation Act.

3.2 Regional Initiatives

While politically difficult to implement, regional initiatives are particularly important because local governments are not empowered or motivated to influence regional land-use patterns in accordance with metropolitan-wide growth management objectives. The Minneapolis-St. Paul metropolitan area has had regional property tax-base sharing in place since the mid-1970s. Under this arrangement, localities pool 40 percent of their tax increase over 1991 assessment for commercial and industrial properties. These combined revenues are redistributed among the localities according to the population and overall tax base of each. Since tax-base sharing began, Minneapolis has moved from a beneficiary to a contributor, reflecting its economic revitalization success, while St. Paul has reduced its share of the recipient pool. Overall, this revenue-sharing has ameliorated the per-capita disparity between the area's richest and poorest communities fivefold (Nelson and Duncan, 1995). Despite complaints from suburban jurisdictions, local officials have stated that, without it, no meaningful regional land-use and development controls could be imposed. The Minneapolis-St. Paul area has recently strengthened regional planning by placing all sewer, transit, and land-use planning under one operational authority, transforming the Met Council from a $40-million-a-year planning agency to a $600-million-a-year regional government (Orfield, 1997).

3.3 National Initiatives

The intent of the following national initiatives is not to replace state and local land-use planning control, but to lend support to local Smart Growth initiatives, demonstrate new alternatives, and articulate the potential cost of allowing current development patterns to grow uncontrolled.

President's Council on Sustainable Development

In 1993, President Clinton created the President's Council on Sustainable Development (PCSD). Until its expiration in June 1999, the PCSD advised the president on new approaches to integrate economic, environmental, and equity issues. The Council comprised a partnership of leaders from business, multiple levels of government, and community, environmental, labor, and civil rights organizations. The guiding mission of the PCSD was to accomplish the following:

- Forge consensus on the identification and development of innovative economic, environmental, and social policies and strategies
- Demonstrate how policy can be translated into actions that foster sustainable development
- Increase the visibility of sustainable development
- Evaluate and report on progress by recommending national, community, and project-level frameworks for tracking sustainable development

Under the umbrella of the PCSD, the Metropolitan and Rural Strategies Task Force addressed the central components of sustainable development–land use, ecosystems, transportation, public safety, and affordable housing–by encouraging local and regional collaboration among federal, state, and local government agencies; public interest and community groups; and businesses in both metropolitan and rural communities.

The Clinton-Gore Livable Communities Initiative

In January 1991, Vice-President Gore initiated a comprehensive Livability Agenda to strengthen the federal role in support of state and local community-building efforts aimed at ensuring a high quality of life and sustainable economic growth. As part of this initiative, the Clinton Administration has proposed that billions of dollars be directed toward investments that support livability programs. Better America Bonds, increased mass transit funding, the promotion of regional collaboration, and school planning are among the major funding areas. More than a million dollars would be dedicated to the purchase of open space, in addition to tax incentives rewarding farmland and parkland preservation. At the same time, the Administration has promised to modify those federal subsidies, such as highway funding, that encourage sprawl. The Livability Agenda integrates the commitments of more than a dozen federal agencies.

Transportation Equity Act for the 21st Century

Some of the alternative transportation investment strategies outlined by the Livability Agenda are funded through the Transportation Equity Act for the 21st Century (TEA-21) that was signed into law in June, 1998. For instance, TEA-21 provides $41 billion over the 6-year authorization for transit programs. This is $10 billion more than that provided under the Intermodal Surface Transportation Efficiency Act (ISTEA), the previous surface transportation bill. The legislation strengthens environmental protection efforts through the continued funding of key ISTEA programs. The Congestion Mitigation and Air Quality Improvement program provides a flexible funding source to state and local governments for transportation projects that help them meet requirements of the Clean Air Act, whether they be transit projects, travel-demand management strategies, traffic-flow improvements, or public fleet conversions to cleaner fuels. Expanded provisions of TEA-21 enable more funds to be used for bicycle facilities and pedestrian walkways, as well as educational programs that address pedestrian and bicycle safety considerations. Other changes in the law ensure the consideration of bicyclists and pedestrians in the planning process. TEA-21 authorizes more than a million dollars for technical assistance and grants to states for the purposes of developing scenic byway programs. The Transportation and Community and System Preservation Pilot program is a comprehensive initiative of research and grants to investigate the relationship between the efficiency of the transportation system and community and environmental goals. Beyond these transportation investments, TEA-21 reaffirms earlier surface transportation policy through its requirement of a nexus between transportation and land-use planning.

Federal Environmental Regulations

While not directly meant to affect development and growth, environmental laws are in place that increasingly necessitate growth management so communities can remain compliant with the law. Presented below is a brief overview of several of these:

- **Clean Water Act (CWA)**. This law focuses on controlling discharges of pollutants to water bodies, including oceans, lakes, rivers, and streams, as well as wetlands. Through this regulation and associated regulatory programs, communities must consider how activities associated with different land uses, particularly commercial, residential, and industrial land uses, will affect their local water resources. Many of the programs implemented under the authority of the CWA, such as the storm water and nonpoint source programs, advocate the preservation of open spaces within communities as an effective means to control the amount of pollutants washed from the land into the water.

- **Coastal Zone Management Act/Coastal Zone Act Reauthorization Amendments (CZMA/CZARA).** The U.S. coastline historically has attracted settlements, resulting in a wide range of uses from industrial and port developments to small fishing villages and high rise condominiums. Preservation and protection of coastal resources, such as beaches, dunes, and wetlands, are the foremost objectives of the CZMA. Communities within states that have a comprehensive coastal zone management plan are encouraged to implement management measures that will prevent the degradation of coastal waters and surrounding ecosystems. The 1980 amendments to the CZMA encourage “special management area planning” to identify in advance those critical ecological resources that need protection. Those designated areas benefit from special protection and programs that serve to manage conflicts between development and resource conservation (Kaiser et al., 1995). An example of this form of critical area analysis is Maryland’s designation of all land within a thousand feet of the Chesapeake Bay as critical areas and subject to special protection.

- **Safe Drinking Water Act (SDWA)**. A strong connection exists between land development and the quality of drinking water. The SDWA acknowledges this connection by promoting watershed protection as a means to protect ground and surface water sources of drinking water. Recent amendments to the SDWA require states to devise and implement source water assessment plans that examine potential land uses that may degrade drinking water sources. Communities use this information collected through the assessment to improve protection of their drinking water supplies by developing a source water protection program. Through improved understanding about the location of and potential impacts to drinking water supplies, communities can use land-use restrictions, such as zoning, to control development within a watershed and potentially reduce the cost of drinking water treatment.

- **Clean Air Act (CAA)**. Good air quality is an important consideration in determining a community’s quality of life. Clean air affects not only human health, but also the aesthetics of a community. The Clean Air Act regulates the amount of air pollutants released by a wide range of sources, including motor vehicles, factories, and small businesses. Each state has goals it must reach for different air pollutants. When these goals are not met, a state must develop and implement a plan to reduce the levels of air pollutants. Communities play an important role in achieving the air quality goals contained in state implementation plans. Efforts to reduce air emissions often cause communities to consider alternatives to traditional development for their air quality benefits, such as investment in public transportation systems versus the creation of more or wider streets.

- **Resource Conservation and Recovery Act (RCRA)**. The focus of this regulation is the proper management of solid and hazardous wastes. RCRA requires thorough documentation of these materials from "cradle to grave." Through RCRA, a community is able to determine the location of firms producing hazardous materials and where haulers dispose of them. This information, such as the location of improperly disposed residues from chemical production, can help communities make decisions about emergency planning, infrastructure investments, and future land-use controls to reduce the risk associated with hazardous and solid waste materials.

- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)**. This regulation, often referred to as Superfund, addresses the problem of improperly disposed wastes and the contaminated lands left behind. Superfund comprises many components, including determining who is responsible for creating the waste site, conducting an assessment of the hazardous substances on a site, and implementing cleanup of the site. Communities with Superfund sites listed on the National Priorities List often struggle with the issue of how to use these vacant lands. The Brownfields program initiated under Superfund helps communities turn these vacant or underutilized sites into productive properties. Safe redevelopment of former Superfund sites allows a community to infill existing developed areas and prevent the pressures of growth from consuming undeveloped lands or greenfields.

- **National Environmental Policy Act (NEPA)**. Mitigating the environmental impacts of federal actions, such as the siting of federal facilities and the issuance of permits and licenses, is NEPA's focus. By requiring the preparation of environmental impact statements (EISs), the federal government examines the likely consequences of proposed actions and evaluates several feasible alternatives. The review process of an EIS allows the public to voice objections to a proposed federal action. Such objections can lead to a modification or cancellation of proposed projects, or a significant delay, thus influencing community development decisions.

- **Endangered Species Act (ESA)**. Compliance with this regulation often requires land-use planning and regulatory mechanisms to conserve the ecosystems on which the species depends. Through the development of Habitat Conservation Plans (HCPs), parties involved in proposed land cover conversion must determine the impacts on the ecosystem of concern, identify steps to minimize those impacts, and describe alternatives to the proposed changes. The process of negotiating and implementing HCPs can alleviate development pressures through the creation of habitat preserves.

- **Executive Order 12898 on Environmental Justice.** President Clinton issued Executive Order 12898 on February 11, 1994, to establish environmental justice as a national priority and ensure that "all communities and persons across this Nation should live in a safe and healthful environment." This was the first presidential effort to direct all federal agencies with a public health or environmental mission to make environmental justice an integral part of their policies and activities. The Order focuses federal attention on the environmental and human health conditions of minority and low income populations–those most susceptible to industrial, hazardous waste, and large transportation infrastructure sitings. The U.S. Department of

Transportation is now focusing more attention on understanding and addressing the needs of these more transit-dependent populations who often find it difficult to access growing employment opportunities in suburban areas.

4.0 The Future of Community Planning

Communities are discovering innovative ways to manage growth so as to enhance its benefits and minimize its costs. In 1999 alone, approximately 1,000 state land-use reform bills were introduced in legislatures across the country (American Planning Association, 1999). Approximately 200 of these bills have been enacted into law, tightening land-use laws, authorizing more innovative and flexible land-use controls, and reforming “business-as-usual” processes. Supported by other local, state, regional and national initiatives, this modernization of planning will provide new opportunities for Smart Growth.

In addition, an increasing number of communities are investing in geographic information systems (GISs) to inventory their land uses, infrastructure, natural and cultural resources, and to automate their mapping needs. A lesser number of these communities are taking full advantage of GIS as an integrated land-use planning and information management tool. Much of the land-use modeling being done today is performed by regional metropolitan planning organizations that largely emphasize transportation system design. Nonetheless, with technology rapidly expanding in scope and availability, more communities will turn to more sophisticated GIS analysis and land-use modeling to meet their analytical needs of today and tomorrow. Through the use of these models, communities can begin to assess the implications of growth, project the outcomes of various planning options, and, ultimately, manage growth in a smarter way.

Appendix D
Key Terms and Definitions

Key Terms and Definitions

The descriptions of the land-use change models summarized in this guide contain terms commonly used in professions such as computer modeling, land-use planning, socioeconomics, transportation planning, and environmental protection and restoration. This appendix provides "plain English" definitions of terms used throughout the guide.

Aggregate Modeling	An approach to travel demand modeling that employs large population aggregates, defined in geographic, social, or economic terms, as the fundamental unit of analysis. In a typical application (such as the regional network-based travel models that rely on coarse-grained zone systems), the variation in key characteristics (such as income and household size) between population aggregates is less than the internal variation subsumed within population aggregates.
Algorithm	A step-by-step approach for computing a solution to a mathematical problem. Solutions to some mathematical problems may be computed by applying any one of several alternative algorithms; the solutions will not necessarily be identical. For example, comparison of traffic assignments computed with different algorithms generally will reveal different numbers of vehicles assigned to a link
Attribute	A piece of information describing a map feature. The attributes of a Zip Code, for example, might include its area, population, and average per capita income. Attribute data is one of the two main types of data in a GIS, the other being spatial data.
Basic Industry	The export sector that sells its goods and services to consumers outside the metropolitan area.
C	A computer programming language.
C++	An enhancement of C that supports object-oriented programming.
Calibration	Testing and tuning of a model to a set of field data not used in the development of the model. Also includes minimization of deviations between measured field conditions and output of a model by selecting appropriate model coefficients.
Causal Models	Attempt to define relationships among system elements. As with time series analysis, past data are important to causal models. A causal model is the most sophisticated kind of forecasting tool. It expresses mathematically the relevant causal relationships. It is, in essence, a mathematical description of the underlying process. Hence, the purpose is not merely to project, but also to explain the process. Regression and econometric models are examples of causal models.
Census Tract	A small, relatively permanent statistical subdivision of a county. Census tract boundaries normally follow visible features, but could follow governmental unit boundaries or other nonvisible features as well. A census tract may contain anywhere between 2,500 and 8,000 people.

Census Summary Tape Files 1a (STF1a) — U.S. Bureau of the Census' 1990 Census Data on population items such as age, race, sex, marital status, Hispanic origin, household type, and household relationship. Population items are cross-tabulated by age, race, Hispanic origin, or sex. Housing items include occupancy/vacancy status, tenure, units in structure, contract rent, meals included in rent, value, and number of rooms in housing unit.

Census Summary Tape Files 3a (STF3a) — U.S. Bureau of the Census' 1990 Census Data on population and housing items, including age, mobility limitation status, occupation, class of worker, place of work, educational attainment, poverty status, employment status, private vehicle occupancy, family type, race, farm and nonfarm population, residence in 1985, school enrollment, group quarters, Hispanic origin, sex, household type and relations, travel time to work, income in 1989, urban and rural population, industry, veteran/military status, means of transportation to work, workers in family in 1989, value of housing unit, mortgage status, vehicles available, occupancy status, year householder moved into unit, year structure built, and rent.

Correlation — A statistical measure of the extent to which two variables behave alike or are related.

Demographics — The statistical characteristics of a population (e.g., income, education, race, and home ownership).

Deterministic — An approach to problem solving that quantifies the results, using an exact model, also referred to as an exact mathematical model. For instance, estimating the time it takes a car traveling at 50 miles/hour to travel 50 miles can be solved using a deterministic approach:

The exact mathematical model is: time (hours) = distance (miles) / velocity (miles/hour) and the exact (deterministic) solution is one hour. The same problem can be solved using a stochastic approach.

Disaggregate Models — In common usage, models developed to represent the behavior of individual decision makers (e.g., persons, households, firms).

Econometric Model — A more sophisticated regression approach often involving a system of interdependent regression equations that describe some sector of economic sales or profit activity. Although expensive, it better expresses the causalities involved than an ordinary regression equation and, hence, should project more accurately.

Empirical — To rely or base something on observation (data). An empirical approach uses existing observation/data to develop relationships to solve a problem (i.e., there is no hard science involved).

Expert System — A modeling approach that incorporates human judgment and expertise, both quantitative and qualitative, in a decision-oriented framework.

Feature	A map representation of a geographic object. Store sites, customer locations, streets, census tracts, and Zip Codes are examples of map features. Features are drawn as points, lines, and polygons in ArcView GIS.
Geographic Information System (GIS)	A configuration of computer hardware and software that stores, displays, and analyzes geographic data. See Section 3.2 of this guide for a more detailed explanation and illustration.
Growth Controls	Tools used to manage growth through limits placed on land use, bulk, and density that include down-zoning, open space acquisition, annual permit limits, and urban growth boundaries.
Hedonics	Of, relating to, or marked by pleasure. With respect to land-use models, hedonics refers to quality-of-life indicators.
Impact Fees	A mechanism used by local governments to offset the impacts a new development will cause. Impact fees are charged to developers seeking a building permit.
Input-Output Analysis	A method for analyzing the uses of capital and labor, the disposition of goods, and the flows of money in an economy within a given spatial setting, and for obtaining a picture of the distribution of economic activity within a region and with respect to a system of regions, through a matrix of coefficients which relate inputs to outputs. Essentially derived from a revenue expenditure accounting system.
Land Suitability Analysis	Determining where it is appropriate to locate new development based on an array of factors (e.g., soil type, slopes, desired preservation areas) often determined by the community.
Layer	A set of related map features and attributes stored as a unique file in a geographic database. A GIS can display multiple layers (e.g., counties, roads, and hamburger stands) at the same time. See Exhibit 3-1 for an illustration of regional GIS layers.
Linear Regression Analysis	A type of regression analysis in which the functional relationship between two or more variables is described by a straight line, as opposed to a curve. Linear regression using the least squares method (defined at regression) is a procedure sometimes used to arrive at trip production and trip attraction rates as a function of land use or household characteristics.

Logit	A choice model formulation based on the principle that individuals maximize utility in choosing among available alternatives. The logit formulation involves specifying a utility function for each individual, with a deterministic component (that is, one which depends on characteristics of the individual and of the alternatives) and a stochastic disturbance (or error term). The form of the logit model follows from the assumption that the error terms are independent and share the same probability distribution. This assumption under certain conditions may produce erroneous results, which can be overcome by using nested logit formulations.
Lowry Model	Incorporates the spatial distribution of population, employment, retailing, and land use within a compact, iterative procedure. Models such as DRAM/EMPAL are successors to the Lowry Model.
Markov Process	A stochastic process that assumes that in a series of random events the probability of an occurrence of each event depends only on the immediately preceding outcome.
Metadata	Information on the content, quality, condition, and other characteristics of data. Useful in understanding and locating data.
Multinomial Logit Methods	A logit model of choice among more than two alternatives.
Nested Logit	A representation of the structure of relationships between travel choices an individual makes based on empirical data that provide the basis for projecting the number of trips that will be made on each mode. A nested logit is used for travel choices that have important similarities (e.g., bus and light rail transit). Conceptually, nested logit analysis involves the grouping of similar alternatives into one or more "secondary" logit models, with a "primary" choice among the bundles of similar alternatives. They can be any number of levels and branches in a nested logit hierarchy, limited only by models through methodical estimation of each standard logit model in the hierarchy.
Non-Basis Industry	The local sector; sells its goods and services within the metropolitan area.
Nonpoint Source Pollution	Pollution that originates from multiple sources over a relatively large area, as opposed to that released though pipes. Nonpoint sources can be divided into source activities related to either land or water use, including failing septic tanks, improper animal-keeping practices, agricultural and forestry practices, and urban and rural runoff from roads and parking lots, etc.
Nutrient Loading	The total amount of pollutants in the form of excess nutrients (usually nitrogen or phosphorous) entering a water body.
Origin-Destination Pairs	Transportation network information about the number of area trips going to and from origins and destinations.

Object-Oriented Programming	A programming style that rigorously integrates data and actions that can be taken on those data into single components called objects (DHS). One example is ArcView's Avenue Script.
Object-Oriented Database	Each data item in a database is related to all others in logical ways, guaranteeing consistency and minimizing the possibility of errors.
Open Space Preservation	A tool used to preserve scenic, natural, and historic resources, including prime agricultural and forestal lands, environmentally sensitive areas such as flood plains, and steep slopes.
Overlay Districts	A land-use tool that is superimposed over existing zoning districts on a particular zone, creating an additional set of requirements to be met when those special resources are affected by proposed development.
Regression Model	Relates the variable being forecasted (i.e., the dependent variable) to other economic, competitive, internal variables (i.e., independent variables) and estimates a regression equation using the method of ordinary least squares. Relationships are primarily analyzed statistically, although any relationship should be selected for testing on a rational basis.
Regression	A mathematical technique for exploring relationships between sets of observations on two or more variables. A functional relationship between the variables is postulated, and a line or curve fit between the plotted observations so as to minimize some function (usually the square) of the deviations between the plotted points and the line or curve. The result is the equation of the best-fit line or curve describing the dependent variable in terms of the other variables, which is often used for projective purposes according to the goodness-of-fit. Several types of regression analyses exist, including time-series, time interval, time step, and temporal resolution.
Sedimentation	Process of deposition of waterborne or windblown sediment or other material. One example would be sediment deposited in a stream as the result of runoff from a construction project. Also refers to the infilling of bottom substrate in a water body by sediment (siltation)**.**
Semi-Empirical	Semi-empirical combines empirical techniques with some science concepts; for example, estimating the dynamic flow of cars at a certain point in a highway can use historical data only on the numbers of cars with time (empirical). When the empirical approach includes some science (e.g., statistical theory), then the approach becomes a semi-empirical one.

Smart Growth	Smart growth recognizes connections between development and quality of life. It leverages new growth to improve the community. The features that distinguish smart growth in a community vary from place to place. In general, smart growth invests time, attention, and resources in restoring community and vitality to center cities and older suburbs. New smart growth is more town-centered, is transit and pedestrian oriented, and has a greater mix of housing, commercial and retail uses. It also preserves open space and many other environmental amenities. But there is no "one-size-fits-all" solution. Successful communities do tend to have one thing in common–a vision of where they want to go and of what things they value in their community–and their plans for development reflect these values. (Source: ICMA and the Smart Growth Network, 1998)
Spatial Data	Spatial data represents the shape, location, or appearance of geographic objects. It can be in vector, raster, or image format. One of the two main types of data in a GIS (the other being attribute data).
Spatial Analysis	The process of modeling space and examining and interpreting the results. Spatial analysis is useful for evaluating suitability and capability, for estimating and projecting, and for interpreting and understanding. There are four traditional types of spatial analysis: topological overlay and contiguity analysis, surface analysis, linear analysis, and raster analysis.
Stochastic	A statistically based approach characterized by randomness. Similarly, the results of the stochastic approach are based on probabilities.
Travel Demand Management (TDM)	Any step that can be taken to reduce the amount of travel in an area or to and from a particular activity center. TDMs include carpooling, transit, and congestion pricing.
Uniform Analysis Zone (UAZ)	Homogenous land units.
Volume to Capacity Ration	A ratio that refers to number of vehicles on a roadway versus the capacity of the roadway.
Validation	Subsequent testing of a precalibrated model to additional field data, usually under different external conditions, to further examine the model's ability to project future conditions.
Vehicle Miles Traveled (VMT)	A unit of measurement used to estimate the impacts related to transportation, such as traffic congestion and pollutant emissions from mobile sources.
Watershed	A drainage basin. The area bounded by a topographic divide in which all water flows into the same water body.

Zone The basic geographical unit for conventional travel demand analysis. A study area is divided into zones, the number and size of which depend on the size and land use patterns of the area, the geometry of the roadway network, the nature of the problem, the computing resources available, census boundaries, and political boundaries. Zone boundaries are defined so that land uses and activities within are homogenous, to the extent practicable.

Zoning The basic means of land use control employed by local governments in the United States today. Zoning divides the community into districts (zones) and imposes different land use controls on each district, specifying the allowed uses of land and buildings, the intensity of such uses, and the bulk of the buildings on the land.

Appendix E
References

References

American Planning Association. 1999. *Planning Communities for the 21st Century*. A special report of the American Planning Association's Growing Smart Project.

American Rivers Association. 1997. *Combating Sprawl to Save Rivers and Communities*.

Beimborn, E., R. Kennedy, and W. Schaefer. 1996. *Inside the Black Box: Making Transportation Models Work for Liveable Communities*. Citizens for a Better Environment and the Environmental Defense Fund. Washington, D.C.

Bureau of Transportation Statistics. *1998 Pocket Guide to Transportation.*

Chang, R., and P. K. Kelly. 1995. *Step-By-Step Problem Solving*. Richard Chang Associates, Inc. Irvine, CA.

Deakin, E. 1995. Land Use Model Conference Keynote Address. In *Travel Model Improvement Program Land Use Modeling Conference Proceedings*. Travel Model Improvement Program. DOT-T-96-09. U.S. Department of Transportation, U.S. Environmental Protection Agency, and U.S. Department of Energy.

Foote, K., and M. Lynch. 1997. *The Geographer's Craft Project*. University of Texas at Austin. Department of Geography.

International City/County Management Association (ICMA) and the Smart Growth Network. 1998. *Why Smart Growth: A Primer*.

Kaiser, E. J., D. Godschalk, and F. S. Chapin, Jr. 1995. *Urban Land Use Planning*. 4th Edition. Chicago: University of Illinois Press.

Katz, B. June 1997. Curb the Sprawl of the Suburbs. *Hartford Courant* and *Philadelphia Enquirer*.

Miller, E., D. Kriger, and J. Hunt. 1999. *Integrated Urban Models for Simulation of Transit and Land-Use Policies*. Transit Cooperative Research Program Report 48. Washington, D.C.: National Academy Press.

Nelson, A. C., and J. B. Duncan. 1995. *Growth Management Principles and Practice*. American Planning Association. Chicago: Planners Press.

National Center for Resource Innovations. 1997. A study conducted for the Washington Post by Frankel and Fehr.

National Research Council. 1998. *Report 39: The Costs of Sprawl–Revisited*. Transportation Research Board. Transit Cooperative Research Program. Washington, D.C.: National Academy Press.

Orfield, M. 1997. *Metropolitics: A Regional Agenda for Community and Stability*. Washington, D.C.: Brookings Institution Press.

PAS (Planning Advisory Service). 1999. Public Investment (memo).

Parsons Brinckerhoff Quade and Douglas, Inc. 1999. *Land Use Impacts of Transportation: A Guidebook.* National Cooperative Highway Research Program Report 423A Washington D.C.: National Academy Press.

Rusk, D. 1999. *Inside Game Outside Game: Winning Strategies for Saving Urban America.* Washington, D.C.: Brookings Institution Press.

Schrank, D., and T. Lomax. 1998. *Urban Roadway Congestion.* Texas Transportation Institute. Texas A&M University.

Sorenson, A. A., R. P. Greene, and K. Russ. March 1997. *Farming on the Edge*. American Farmland Trust and Center for Agriculture and the Environment, Northern Illinois University, DeKalb, Illinois.

Southworth, F. 1995. *A Technical Review of Urban Land Use-Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies*. Oak Ridge National Laboratory Report 6881, U.S. Department of Energy.

Sumner, S. 1992. *Management Information Systems: The Manager's View.*

Taha, H. A. 1976. *Operations Research: An Introduction.*

USDOT. 1997. *Transit Trends Over Time: Population Oregon: A Comparison with 20 Cities of Similar Transit Service District Population Size, 1990-1995.* National Transit Database (metro publication).

USDOT/FHWA. 1999. *Transportation Air Quality: Selected Facts*. FHWA-PD-99-015.

USDOT/USEPA (U.S. Department of Transportation/U.S. Environmental Protection Agency). Alternative Choice Print Ad "Mass Transit" for *It All Adds up to Cleaner Air* campaign.

U.S. General Accounting Office. April 1999. *Community Development: Extent of Federal Influence on "Urban Sprawl" Is Unclear.* Report to Congressional Requesters.

Washington State Department of Ecology. 1997. *Breathing Easier* (fact sheet).

Weitz, J., and T. Moore. 1998. Development Inside Urban Growth Boundaries: Oregon's Empirical Evidence of Contiguous Urban Form. *Journal of American Planning Association*, 64(4): 424.
August 1, 2000