DEVELOPMENT OF A COMMUNITY-ACCESSIBLE URBAN SPRAWL IMPACT ASSESSMENT SYSTEM IN NORTHEAST OHIO 15-COUNTY REGION FOR THE EMPACT PROJECT

PHASE ONE REPORT

Literature Review For Urban Growth Modeling And Environmental Impact Analysis

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Executive Summary

This report presents the results of literature review for the Phase One task of the proposed project:

Development of a community-accessible urban sprawl impact assessment system in Northeast Ohio 15-county region for EMPACT project *(US EPA Grant #985989-01-0)*

The first part of the report discusses urbanization and urban growth as environmental issues. This is followed by reviews of various approaches currently available for environmental impact analyses.

The second part of the report reviews the urban growth models with recommendations made specifically for Northeast Ohio 15-county region based on local conditions and available databases.

PART ONE: URBANIZATION AND ENVIRONMENTAL IMPACT ANALYSIS

INTRODUCTION

In recent years, Northeast Ohio has seen significant expansion of urbanized areas. This sprawling expansion comes at a price of inefficient land use patterns and impacts to environmental quality in the region. The concerns for land use encompass avoiding sprawl of urbanized lands while preserving environmental quality at both regional and neighborhood levels. As such, efforts are being made to examine the issues in search of better means of controlling and managing urban growth for sustainable environment.

In this part of the report, we first discuss urbanization as an environmental issue to establish the foundation of this review. Next, we discuss various means of environmental analysis via reviewing various models that have been suggested by various research institutions and government agencies.

Given that a wide variety of subjects can be included as possible environmental issues and the limited space in this report, it is not our intention to review in detail all of the individual attempts for modeling specific aspect of environmental impacts. Consequently, the focus is placed on reviewing the different approaches to conducting environmental analysis as related to the control and management of urban growth in the context of Northeast Ohio region. Moreover, there are numerous models with computerized implementation available from commercial or public entities. Again, we review only those that we recognize as possible alternatives to be adapted in Northeast Ohio 15-county region.

With the environmental analysis reviewed in this part, the second part of the report provides reviews of existing models of urban growth. Whenever appropriate, the review of urban growth models will incorporate environmental issues in the evaluation of the models. In concluding this report, recommendations are proposed for the Northeast Ohio 15-county region.

URBANIZATION AS AN ENVIRONMENTAL ISSUE

The expansion of urbanized areas does impact on the quality of the environment. It often degrades the environment in the forms of inefficient land use and air and/or water pollution. When lands are not efficiently used, growth of urbanized areas often became uncontrolled and often penetrated into environmentally sensitive areas such as floodplains, wetlands, steep slope areas, and others. This type of inefficient growth of urbanized areas often proceeds in a leap-frogging fashion that skips usable lands in between new developments, thus creating sometimes smaller patches or vacant lands that are difficult to use. Growth of urbanized areas no doubt increases the amount of air and water pollutions that eventually impact on the quality of our environment.

Even though pollution and environmental degradation do not just happen in urbanized areas, they are usually the most intense and evident in cities and their immediate surroundings. Furthermore, certain types of problems such as the extreme concentrations of wastes that cannot be degraded through natural processes, and congestion resulting from high population densities, are distinctly urban in origin.

There are two types of urbanization problems that are of increasing concern to public officials and the public:

1. Urban population growth – this is currently receiving the greatest attention, and relates to the rate and magnitude of population increase in urban centers. Rapid growth threatens to degrade the natural environment and to overtax urban service systems.

2. Urban sprawl – this is an equally important problem that concerns the inconvenient and inefficient land use patterns of contemporary American cities. These low density sprawling arrangements of urban activities have widely separated places of residence from recreation, employment, shopping and other centers, at the expense of personal convenience and travel costs. The *cost of sprawl* in terms of access to urban institutions, travel time, and wasteful use of urban land has been well documented (Council on Environmental Quality 1974, Nelson *et al*. 1995).

The concern for the protection of the natural environment and maintenance of the existing *character of the community* has caused a basic philosophic shift in citizen attitudes about growth. The result has been a widespread and rapid growth of environmental programs based on the notion of *local no-growth* idea. Environmental groups have been organized to halt expansion of pollution producing industries, and citizens generally have clamored for *down zoning* (lower residential densities), moratoriums on housing and commercial construction, and other growth restrictive measures.

Sprawling without proper management in serving the expanding populations has prompted the search for methods to control urban growth by limiting both territorial and population increases. And yet, urban growth management presents one of the great paradoxes facing the contemporary government officials as well as various concerned citizen groups.

Growth itself is not always undesirable. But desirable urban growth is often associated with economic growth that is socially and environmentally sustainable, balancing economy and ecology. Two major environmental concepts influence contemporary thinking about sustainable development (Ledec and Goodland 1988). The traditional concept is one of *environmental services,* those beneficial functions (such as maintenance of water-flow patterns and recycling of wastes) that natural areas perform. The newer concept is one of *biological diversity*, the full range of genetic diversity (plant and animal species and populations) and ecosystems (in which the plants and animals exist).

Environmental services are the economically valuable benefits to society that natural areas provide. These include creation and protection of soil, stabilization of water-flow patterns, amelioration of climate, breakdown of pollutants, recycling of wastes, provision of fish nurseries, and protection against weather change.

Biological diversity includes three elements: (1) the number and geographic distribution of ecosystems (communities of plants, animals, and their environment); (2) the number and geographic distribution of animal and plant species, and (3) the genetic variation within each species (Ledec and Goodland 1988).

Both concepts are threatened by development of urbanized areas because they are public goods that do not carry a market price tag. Development-environment interactions may be positive or negative, but they are rarely neutral.

Positive impacts of development are those that maintain biological diversity and environmental services. For example, an environmentally positive local land use plan would manage development so as to conserve:

(1) areas of highly erodible soil through preservation of existing slopes and vegetation;

(2) prime agricultural lands through encouragement of sound farming practices and location of future urban growth outside of farming areas;

(3) watercourses, floodplains, and wetlands that make up natural drainage and aquifer recharge systems through conservation of such natural areas as forests and vegetated stream buffers that regulate water flow and adoption of impervious surface limits and other standards to regulate runoff from urban development;

(4) airsheds with high air quality through location of such stationary sources as new power plants and transportation routes in downwind areas; and

(5) habitats of rare or endangered species through maintaining a connected critical mass of natural areas adequate to support plant and animal populations.

Negative impacts of development are those that damage biological diversity and environmental services. These may include:

(1) displacement or damage of natural areas by intruding development; and

(2) pollution of environmental media (air, water, land) by such urban residuals as stormwater runoff or automobile and industrial emissions.

In the case of displacement or damage, the primary remedy is to locate and manage future urban land uses so as to maintain the natural functions and biological diversity of the environment. In the case of pollution, the primary remedy is to reduce the generation of pollutants at the source as well as mitigate their environmental effects.

To further understand the impacts to our environment by undesirable sprawl and how it can be managed, it is necessary to overview the various approaches being proposed and in some cases, tested. An early example of growth control approaches was the restrictive *large-lot zoning regulations* adopted by many suburban communities in response to the rapid urbanization of the 1950s. This type of zoning regulation was for the express purpose of preventing overtaxing of public schools and public utilities and for retaining the character of relatively low density in the countryside. In reality, the practice was also for class and socio-economic segregation.

Cluster development evolved as another alternative settlement pattern in growth control, adapted in the 1970s. *Clustering* was not originally conceived as a design technique where dwellings were arranged around *cul-de-sac*s, the common application of the term in contemporary subdivision planning. Dwellings were arranged in small clusters to facilitate utility construction, rather than scattered about on large tracts. Clustering did not propose a higher gross density per square mile than that authorized under large lot zoning, but permitted an increase in net densities so that open space could be held in common in large tracts, thereby protecting open space.

In the contemporary practices, a wide range of growth management techniques, each focuses on different objectives with different approaches have been proposed and tested. Kaiser *et al.* (1995) provides an in-depth summary of these techniques as the following:

- Managing growth by implementing limits to the growth in pre-defined extent
- Managing growth by controlling / defining the urbanizing territory
- Managing growth by controlling / defining environmental degradation
- Managing growth by implementing particular fiscal policies to control growth
- Managing growth by implementing comprehensive planning.

The widely varying objectives of programs for the control and management of community growth largely reflect the different constituency interests that shape each program. Local conditions and interests largely dictate the goals to be achieved by the local growth control and management programs as well as specific processes of decision-making.

Established suburban communities have become alarmed at the threat of increased taxes and the overwhelming burden of local services resulting form uncontrolled population expansion. Rural communities near metropolitan growth centers fear the destruction of their intimate neighborly relationships and slower paced style of life. However, most current growth control measures have as their objectives the protection of the natural environment and the preservation of certain special qualities of community life.

Given the concern for urbanization as an environmental issue, it is then necessary to examine various alternatives to carrying out environmental analysis as a means of assessing impacts on our environment as caused by the expansion of sprawling urban areas. In the next section, we review five alternative approaches to conducting environmental analysis with comments for their suitability for the Northeast Ohio 15-county region.

ENVIRONMENTAL ANALYSIS

Environmental analyses include environmental impact analysis, cumulative impact assessment, critical area analysis, and hazard analysis. For computerized implementation of environmental analytic models, we review three systems: (1) the AGNPS system by the Agricultural Research Services, (2) the BASINS system released by the US EPA and (3) the LTHIA model developed by Jonathan Harbor and his colleagues at Purdue University.

Environmental Impact Analysis

The National Environmental Policy Act of 1969 created the concepts of environmental impact analysis, which has spread around the world. Originally aimed at requiring federal agencies to prepare environmental impact statements (EIS) for actions that could significantly affect the environment, the concept also is in use by many states and local governments. Proposed public or private development projects trigger environmental impact analyses The focus is on potential negative impacts of the proposal or alternatives to the proposal and how they may be mitigated.

The general structure of an environmental impact analysis is to describe (Burchell and Listokin, 1975):

1. present conditions in the project area;
2. the proposed project;
3. probable short- and long-term negative and positive impacts of the proposed project;

4. alternatives to the proposal (engineering, design, location, etc.);
5. probable short- and long-term negative and positive impacts of alternatives; and
6. recommended action, including techniques to mitigate unavoidable negative impacts.

Four of the various environmental impact analysis techniques are especially useful: (1) the descriptive checklist; (2) the trade-off matrix; (3) the spreadsheet model; and (4) the overlay screening model.

DESCRIPTIVE CHECKLISTS

This technique provides systematic procedures for ensuring that all relevant impacts are examined for each proposed project that falls within the range for required environmental impact analysis (Westman 1985). That range will vary with the size, type, and scope of the project; smaller projects are typically exempted. The *checklist* poses a series of questions about the impact of the project on the environment (e.g., will the project impede natural drainage patterns), as well as the impact of the environment on the project (e.g., will the project be subject to floods or mud slides). *Checklist* content should be determined by local environmental conditions. The general headings of an illustrative checklist might include (Westman 1985):

1. Air quality impacts
   a. Public health

    b. Land use
2. Water quality impacts
    a. Groundwater
    b. Surface water
3. Soil erosion impacts
4. Ecological impacts
    a. Plant
    b. Animal
5. Noise impacts
6. Hazard impacts
    a. Natural
    b. Man-made

Checklists have the advantages of promoting systematic thinking about impacts and summarizing effects in a concise format. However, checklist-based analyses may not be specific enough to capture all impacts, may not identify the interactions between effects, may overlook the distributional aspect of impacts, and may be so qualitative and subjective that their findings cannot be replicated or tested.

While the *Checklist* approach is simple to use and conceptually straightforward, it is limited to analyzing impacts to environment in lumped or aggregated geographic units. It is feasible to adapt this approach for the case of Northeast Ohio. However, better approaches exist as those being discussed below.

TRADE-OFF MATRICES

This technique links the substantive impacts of checklists to the affected groups. As proposed by Westman (1985, 159-62), a simple *trade-off matrix* would list the positive and negative impacts of each feature of a proposed project along the top (column) axis and the affected groups along the side (row) axis. It would express impacts in the cells in both verbal and qualitative terms and in monetary or physical units. Weighting of the cells can be assigned by the decision-makers based on local conditions.

Trade-off matrices have the advantages of clearly stating the effects of each impact on each affected group in whatever terms are appropriate, of permitting flexibility in using available information, and of avoiding the insertion of individual planner's judgments in determining the importance of groups or impacts. Disadvantages are the potential large size of the matrix and the difficulty of summarizing net benefits and costs because a ground total index is not calculated. However, the use of a grand total is not always a good idea because it obscures individual impact information and may distort the importance of various elements.

Similar to the *Checklist* model, the *Trade-off matrices* work with aggregated geographic units so it is not preferred for the case of Northeast Ohio.

SPREADSHEET MODELS

This technique is a recent development in impact analysis techniques. It uses the capabilities of spreadsheet programs to rapidly perform complex matrix relationships based on algebraic formulas that the user puts in. This is particularly useful for calculating linked sequences of outcomes in large data sets, where the output from one formula is the input to a following formula. Its relative simplicity fits well with the types of database likely to be available in impact analysis.

Spreadsheet models have the advantages of user friendliness due to menu driven software; readily accessed data files; transparency of structure; rapid recalculation of the impacts of changes in the data, formulas, or parameters; and simplicity of construction and operation. Disadvantages are the necessity of considerable technical skill to set up the formulas and structure of the spreadsheet and the need to transform all data to similar units, such as dollars or amounts of a particular pollutant.

Again, this model is similar to the *Trade-off matrices* approach. Consequently, it is not preferred for the EMPACT project in Northeast Ohio.

OVERLAY SCREENING MODEL

Originated from McHarg's approach (McHarg 1969), this technique relies on the cumulative impact analysis (see below) capabilities afforded by overlaying separate impact maps. *Overlay screening* models are useful in reviewing the aggregate impacts of pollution on such natural resources as groundwater. For each impact map, three elements are considered: (1) weights; (2) ranges, and (3) ratings. The model assigns weights to each of the impact factors and then rates the steps in the range for that factor on a scale from one to ten. The model simply adds the numerical values determined by multiplying each factor weight by the rating associated with a range value of that factor at the location being assessed.

Screen overlay models have the advantages (1) of allowing an estimate of impacts in a complex system by combining separate estimates of impacts on individual factors; (2) of being "transparent" in terms of the operations of the model, and (3) of being well suited to use in GIS operations, where the impacts can be rapidly calculated and recalculated. Disadvantages include the necessity to compile considerable data about the various factors, to use expert knowledge to estimate the weights, and to avoid the impression that the model outputs the absolute values rather than relative estimates.

This approach is structurally simple to implement if data are available. It also corresponds to the prevailing GIS functions available in most GIS packages. Consequently, it is being used by many of the urban growth models being reviewed in the second part of this report.

CUMULATIVE IMPACT ASSESSMENT

This technique tracks the aggregate effects of individual impacts on the environment. A cumulative impact assessment uses an environmental inventory and regular environmental indicator monitoring, together with a running tabulation or modeling of the impacts of all existing and proposed projects, to look at the total effects. Cumulative impact assessment is typically applied to multiple projects over a multiyear period at the same sites.

Contant and Wiggins (1990) point out that cumulative impacts result from both similar and dissimilar actions accumulating over space and time to produce natural systems changes that are incremental and synergistic as well as immediate and delayed. They also noted that some actions are growth-inducing and change potential future activity or natural system response.

CRITICAL AREA ANALYSIS

The Model Land Development Code of the American Law Institute (1976) proposed state designation of "areas of environmental concern"; the Coastal Zone Management Act of 1972 (CZMA) required that states designate "areas of particular concern"; and the 1980 amendments to CZMA encouraged "special area management planning" (Godschalk 1987, Brower and Carol 1987). Critical areas are designated to conserve sensitive environments or natural areas such as wetlands, barrier islands, estuaries, endangered species habitats, or water supply reservoir buffers.

Unlike impact analysis, which is a responsive technique, critical area analysis is a pro-active technique. The land use planner can use critical area analysis to identify in advance the areas that will need special management in order to protect their environmental services or biological diversity. This is also a technique that has been implemented in the Portage County model reviewed in the second part of this report.

HAZARD ANALYSIS

This technique includes considerations for floods, hurricanes, earthquakes, landslides, and ground subsidence. Based on occurrence histories and seismic analysis, natural hazard maps can be prepared to enhance the inventory of environmental database which, in turn, is used in the process of land use planning.

Man-made hazards often result from the leftovers or residuals from technological processes such as chemical production or inadequate waste disposal. Concentrations of hazardous wastes in soil or groundwater can pose public health threats as well as legal liability threats. These may include other pollution hazards such as underground storage tanks, sanitory landfills, agricultural fertilizers, pesticides, livestock wastes, urban stormwater, septic tank drainfields, mineral extraction processes, and accidental spills of hazardous materials.

COMPUTERIZED SYSTEMS FOR ENVIRONMENTAL ANALYSIS

The three systems to be reviewed here are (1) the AGNPS system by the Agricultural Research Services, (2) the BASINS system released by the US EPA and (3) the L-THIA system developed by Purdue University. The three systems deal with environmental impacts with regard to non-point source pollution and other related aspects.

AGNPS

The *AGNPS*, Agricultural Non-Point Source, model is a distributed model developed by Agricultural Research Service (ARS) scientists and engineers. With studied area partitioned into a grid of raster cells as its operational unit, *AGNPS* predicts soil erosion and nutrient transport/loading from agricultural watersheds for realistic or hypothetical storms. It is an event-based system in which input parameters are structured to describe the event being evaluated for modeling of erosion. Typically the size of cells in the grid ranges from several hundred square meters to hundred acres.

AGNPS initially was developed in FORTRAN computer language and made available to researchers. Recently, however, it has been ported to work with GIS systems such as *GRASS* (Army Corp of Engineers) and *Arc/Info* (Redlands, California). In its original format, *AGNPS* can be run in either as a *lumped model* or as a *distributed model*. It takes input of 22 parameters that include soils, slopes, aspects, elevations, land use, management practices, fertilizer or nutrient inputs, type of machinery used, channel slope along with information about watershed, precipitation, and locations of outlet cells. It then applies Universal Soil Loss Equation to model erosion, EI-Index for precipitation, and Soil Conservation Service Curve Number technique for hydrological analysis.

AGNPS has long been used by researchers to estimate and evaluate non-point source pollution with respect to agricultural activities. It is widely used and has been revised to fit various needs in different studies. As the computer codes are free and can be modified, it seems to be a potentially useful model for the

Northeast Ohio 15-county region at sub-regional level. However, the high demand of data (22 parameters are needed to feed the model) prohibits the adoption of this model for practical use in the region because these required data are not available to all areas in the 15-county region.

BASINS SYSTEM

The BASINS system was released by the US EPA as a multipurpose environmental analysis system for use by regional, state, and local agencies in performing watershed and water quality-based studies. BASINS makes it possible to quickly access large amounts of point source and non-point source data in a format that is easy to use, easy to understand. Installed on a PC Basins allows the user to access water quality at selected stream sites or throughout an entire watershed. It is an invaluable tool that integrates environmental data, analytical tools, and programs to support development of cost-effective approaches to environmental protection.

The BASINS system can be downloaded from its home pages or via ordering over WWW. It comes in customized sets of CD-ROMs that contain the programs, an extensive collection of environmental database, and a volume of user's guide. The system is implemented as project files in the format of ArcView GIS.

When used to perform environmental analysis, the well structured data layers are essential in supporting analysis of environmental impact by polluting chemicals, non-point source pollutions. The BASINS system generates reports in tables that list various polluting sources and statistical charts that summarize the impacts caused by the selected chemicals. It is a well designed and well implemented system.

While the BASINS system is indeed very powerful in supporting tasks of environmental analysis for Northeast Ohio 15-county region with its fairly complete data layers, the large number of various chemicals and pollution definitions may be confusing for citizens who have not been trained to comprehend such materials. As such, the BASINS system is more appropriate for professionals or those with background in the areas of environmental impact analysis. Moreover, the BASINS system is deeply rooted in ArcView GIS software that is very difficult to modify into programs executable over the Internet.

LTHIA

The *LTHIA* (Long-term Hydrological Impact Analysis) model was created by Jonathan Harbor and his colleagues at Purdue University to examine the long-term effects of land use changes caused by urbanization. This model estimates the changes in runoff, recharge, and nonpoint source pollution resulting from past or proposed land use changes. It provides long-term average annual runoff for a land use configuration, based on actual long-term climate data for the study area. The estimates by *LTHIA* are assisted by long-term climate data with a focus on the average impact, rather than extreme year or individual storms.

LTHIA does not predict what will happen in a specific year but was intended to be a quick each way to estimate hydrologic impacts of different land use scenarios. Specifically, the results from *LTHIA* can be used to generate community awareness of potential long-term problems and to support physical planning aimed at minimizing the disturbance of critical natural areas.

LTHIA takes input information, for the study area, that includes

- Location of the studied area,
- Zoning maps,
- Precipitation data,
- Past, present, and future land uses, and
- Hydrological soil groups for land use areas.

LTHIA then determines runoff from precipitation data and a land use / soil index, and the curve number to support its analysis of nonpoint source pollution.

For output, *LTHIA* provides estimates of changes in runoff as caused by changes of land use. This information can be used to evaluate the amount of nonpoint source pollution as part of overall environmental analysis.

LTHIA was developed first to run on PC but is now being converted to run over WWW. We see this model as one that has high potential to work with models we recommend for evaluating urban growth in the Northeast Ohio 15-county region. Consequently, we recommend collaboration between the OHIO EMPACT project and Purdue University team to further integrate the results from both ends.

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PART TWO: LAND USE DEVELOPMENT MODEL REVIEW

INTRODUCTION

Urban development in the United States since the 1950s has been dominated by the movement of residential, commercial, and industrial land uses to the urban fringe and the conversion of rural areas near major metropolitan areas into low-density, predominantly single-family residential subdivisions and strip commercial developments. These development patterns, commonly referred to as "urban sprawl," result in haphazard, low-density development patterns which consume large quantities of valuable agricultural land and generate excessive public costs of providing required community facilities and services. As a result, the issue of urban sprawl has attracted a great deal of public interest and academic attention (see, e.g., Audirac and Zifou 1989; Burchell, et al. 1998).

The last forty years has also witnessed a continued effort to develop computer-based models for describing urban development patterns and determining the future impacts of public policy choices (Harris 1985; Batty 1994; Wilson 1998). These efforts have generated a voluminous literature (Klosterman 1994; Southworth 1995) but few operational models. However, this situation is changing rapidly as dramatic advances in computer technology and the availability of large quantities of spatially referenced data are stimulating a renewed interest in urban modeling in the United States and throughout the world (Wegener 1994).

This report will review and evaluate ten currently available, fully operational land use development models that can be used to address the environmental degradation and human health impacts of urban sprawl in the 15-county Northeast Ohio region. The review will consider academic and commercially available models to identify the model, or modeling approach, that is most appropriate for considering the implications of urban sprawl and alternate growth management strategies in Northeast Ohio. The review updates and extends similar reviews by Wegener (1994; 1995), the International Study Group on Land-use / Transport Interaction (Webster, et al. 1988; Webster and Pauley 1991), and Southworth (1995).

The models to be considered in this review are: (1) *METROPILUS*, the latest version of Steven Putman's *DRAM/EMPAL* family of models; (2) the first California Urban Futures (*CUF-1*) model developed by John Landis and his colleagues in the early 1990s; (3) the second California Urban Futures (*CUF-2*) model developed by John Landis and his colleagues in the late 1990s; (4) the Portage County, Ohio, model developed by Jay Lee and his colleagues; (5) the *What if?* model developed by Richard Klosterman and his colleagues; (6) the *SmartPlaces* model distributed by the Electronic Power Research Institute; (7) the *TRANUS* model developed by de la Barra and his colleagues at Modelistica, a Venezuelan company; (8) the *UrbanSim* model developed by Paul Waddell and his team at the University of Washington, and (9) the Medina County model developed by Chengri Ding and his colleagues at Cleveland State University.

The report begins by briefly describing the ten models. It then evaluates the models with respect to the following considerations: (1) cost; (2) their ability to work with the data which are, or will become, available as part of this project; (3) the potential for viewing model results via the World Wide Web; (4) the understandability of the model assumptions and operations for non-technical experts; and (5) the theoretical soundness of the model results. It concludes by recommending one model to be used for sub-regional (*i.e.,* county and sub-county) analyses and two closely related models to be used for the fifteen-county regional analysis.

DESCRIPTION OF MODELS

METROPILUS

METROPILUS, the METROPolitan Integrated Land Use System, is the latest urban simulation model developed by Steven Putman and his colleagues at the University of Pennsylvania. Earlier versions of his models (components of which have had several different names including DRAM, EMPAL, ITLUP, and PLUM) are the most widely applied models of household and employment location and land use change ever developed (Putman 1995).[i] Development of the models began in the early 1970s and is continuing. The models have been used in eight of the ten largest cities in the United States and over 20 metropolitan statistical areas including Atlanta, Chicago, Dallas / Ft. Worth, and Los Angeles. The model's theoretical foundations and computational procedures have been extensively documented (see e.g., (Putman 1983; 1992;, and 1995). Detailed descriptions of the models application to San Diego (San Diego Association of Governments 1994)and Chicago (Northeastern Illinois Planning Commission 1998) are also available.

The *METROPILUS* model integrates a residential location model (DRAM), an employment location model (EMPAL), and a land consumption model (LANCON) with ArcView and a easy-to-use graphical user interface. The system provides greatly increased data analysis and manipulation capabilities and seamless integration with the EMME2 and TRANPLAN transportation modeling packages. The following discussion briefly describes the major system components, the model calibration process, and the system outputs.

DRAM. *DRAM*, the Disaggregated Residential Allocation Model, forecasts residential locations by allocating employees (located by their place of work) to residential zones on the basis of: (1) the residential attractiveness of different residential zones, and (2) travel times and / or costs between the work and residential zones. The zones' attractiveness is based on: (1) the extent of the current vacant and developable land, (2) the percentage of the developable land which has been developed, (3) the quantity of the current residential land, and (4) the socio-economic status of the zone's current residents. The relative importance of these variables for a particular application is determined by the model calibration process. The model is a modified version of the standard singly constrained spatial interaction (or "gravity") model that incorporates a multivariate, multi-parametric attractiveness function and consistent procedures for specifying residential zone and / or employment sector-specific constraints.

EMPAL. *EMPAL*, the EMPloyment Allocation model, forecasts employment locations by allocating households (located by their place of residence) to alternative work zones on the basis of: (1) the employment attractiveness of different zones (2) travel time and / or cost between home and work, and (3) the current location of the region's residents and workers. The relative importance of these variables is determined by the model calibration process. Like *DRAM*, *EMPAL* is a modified version of the standard singly-constrained spatial interaction model. The modifications introduced into *EMPAL* are: (1) a multi-parametric attractiveness function, (2) procedures for specifying zone- and / or sector-specific constraints, and (3) a variable which relates the future employment in a zone to its current employment.

Together *DRAM* and *EMPAL* can be used to produce: (1) employment location forecasts that reflect changes in the location of households; and / or (2) household location forecasts that reflect changes in the location of employers. A third model *LANCON*, for LANd CONsumption, takes the calculated demands for residential and employment uses in each zone and estimates the change in each land use category. The models work with between 100 and 300 zones, each of which can contain between 6,000 and 10,000 people. The model also works with between four and eight household types, specified by income and place of residence, and four to eight employment types, located by place of employment.

Model Calibration and Outputs. The *DRAM* and *EMPAL* models are calibrated for a particular study area by fitting the model parameters to the data which describe the region. The models' equations are nonlinear and the data for which the parameters must be estimated are not normally distributed. As a result, a computer program called CALIB (for CALIBration) is used to fit the model parameters. The reliability of model calibrations for the base year is typically between 70 and 90%. The validity of the model forecasts is generally above 90% when local inputs are incorporated into the models.

Model outputs include: (1) the projected employment and residential land uses by zone, (2) the model parameters, (3) several goodness-of-fit significance test statistics, and (4) location elasiticities which measure the relative sensitivity of model outputs to different model inputs. In addition, the model generates a set of land use- and zone-specific residuals which measure the extent to which variations in the model's dependent variables were not explained by the calibration process. These residuals are stored in so called "K-factors" which can be used to increase or decrease the attractiveness of particular zones for locating a particular land use. These variables provide a mechanism for allowing local knowledge of special circumstances which were not included in the model variables to be quantified and incorporated directly into the model.

In a typical application (Northeastern Illinois Planning Commission 1998) *DRAM/EMPAL* (the forerunner to *METROPILUS*) was used to explore two growth scenarios for the Chicago area. The first, "Trends," scenario assumed a continuation of current decentralized land use trends, the expansion of air service capacity at existing airports, and no additional investment in ground transportation infrastructure beyond committed projects. The second, "Infill/Redevelopment" scenario assumed increased development densities around eight selected rail stations, the implementation of agricultural protection policies, increased or stable employment levels in older urban areas in the region, and no additional investment in ground transportation beyond committed projects.

FIRST CALIFORNIA URBAN FUTURES MODEL

John Landis and his colleagues at the University of California, Berkeley, have developed two of the first GIS-based urban models. The models are similar in their overall design but different enough in their details to require separate discussions. The first model, California Urban Futures Model I (or *CUF-1*), will be discussed in this section. The second model, California Urban Futures Model II (or *CUF-2*), will be discussed in the following section.

CUF-1 projects the location, pattern, and density of residential population growth in the fourteen-county Northern California Bay Region through the year 2010, as a function of alternative regulatory and investment policy initiatives.[ii] The model is substantially different from the traditional spatial interaction models such as Putman's METROPILUS model in several ways. Unlike most metropolitan forecasting models which project population growth at the regional level and then allocate it to zones, *CUF-1* allocates growth to individual sites and then aggregates upward to cities and counties. Instead of relying on transportation accessibility as the primary determinant of urban development patterns, *CUF-1* uses spatial accessibility (measured as buffers around locations rather than as network travel times) as one of many variables that determine the location of new development.

CUF-1 was also the first metropolitan simulation model to use a geographic information system (GIS) to assemble, organize, manage, and display the millions of available pieces of information describing land development potential. It was also unique in explicitly allowing realistic development policies to be incorporated directly into the growth forecasting process and allowing the results of different policy scenarios to be viewed in a matter of hours in map form. The influence of the *CUF-1* model is reflected in the fact that two of the other models to be considered here, the Portage County model and the What if? Planning Support System, are based directly on the concepts first outlined in this model.

The *CUF-1* model is built on two primary units of analysis: (1) incorporated cities and counties, and (2) developable land units (DLUs). Population growth, the demand side of the model, is based on projected growth trends for cities and counties. Development potential, the supply side of the model, is calculated in terms of DLUs. DLUs are currently undeveloped or underdeveloped areas inside and outside cities which are candidates for development or redevelopment. They are generated by using GIS overlay functions to combine different GIS layers into a single layer containing a variety of environmental, market, and policy attributes. For example, a DLU might be a currently undeveloped site with steep slopes, that is served by sewers, zoned for light industrial, and less than 500 meters from a major freeway.

CUF-1 "grows" the fourteen-county Northern California Bay Region by allocating projected residential land use demands in each projection period to DLUs as a function of: (1) the projected population growth in each city and county; (2) the profitability potential of each DLU (if developed); and (3) a series of user-specified development regulations or incentives. The analysis is conducted by four closely related sub-models which are described briefly below.

Bottom-Up Population Growth Sub-model. This sub-model is the demand side of the *CUF-1* model and consists of two regression equations. The first equation projects city-by-city population growth at five year intervals for 112 incorporated cites; the second equation projects county-wide population growth at five-year intervals. The equations were developed by applying ordinary least squares regression to a database that combined county- and city-level cross-sectional data and time series data for five-year periods. The equations project future population as a function of: (1) an area's past population trends and (2) variables that provide a "brake" on future population growth, e.g., whether the community had adopted a population, housing, or development cap.

Spatial Database. The spatial database consists of a series of ARC/INFO layers that describe the environmental, land use, zoning, current density, and accessibility characteristics of all site in the fourteen-county Northern County Bay Region. The layers include: (1) TIGER/Line data on roads, census tracts, city boundaries, hydrology, and other features such as railroads and airports; (2) the boundaries for each city's "sphere of influence," i.e., incorporated and unincorporated areas over which cities have some measure of land use control; (3) slopes; (4) buffers around major state and federal roads and existing urbanized areas; (5) earthquake faults; (6) prime agricultural land; (7) marsh and wetlands; and (8) sewer and water utility service costs.

Spatial Allocation Sub-model. The spatial allocation sub-model is a series of decision rules for allocating projected population growth to DLUs. The allocation process proceeds by the following steps: (1) all undeveloped DLUs are scored according to their profitability if developed; (2) DLUs that are not suitable for development due to environmental, ownership, or public policy reasons are eliminated from consideration; (3) the remaining DLUs in each city and its sphere of influence are ranked from high to low with respect to their potential development profitability; (4) the projected population for each city is allocated to DLUs in order of their development profit potential (high to low) at population densities consistent with current market conditions and zoning and general plan requirements.

The allocation process for a city is completed when: (1) all of the projected population growth has been allocated, or (2) there is insufficient undeveloped land to accommodate all of the forecasted population growth. In the second case, the unallocated population growth is accumulated for re-allocation to unincorporated areas. A similar procedure is used to allocate the projected county population (and any unallocated spill-over from cities) to DLUs in the unincorporated county.

The profitability potential for each DLU is equal to the total profit that a homebuilder would expect to realize on the construction of a many new houses as the DLU can accommodate. This profitability is based on a number of factors including: (1) new home sales price; (2) raw land price; (3) hard construction costs; (4) site improvement costs; (5) service extension costs; and (6) development, impact and planning fees. The data required to estimate these variables were obtained from surveys of regional homebuilders and local public works and engineering departments.

Annexation/Incorporation Sub-model. The final component of the model determines whether newly developed DLUs will be: (1) annexed into existing cities, (2) part of newly incorporating cities, or (3) remain as they are. This sub-model consists of a simple regression model that relates the cities' 1980-1990 annexation activity to their population, density, location, and growth policies.

The *CUF-1* model has been used to analyze three alternative regional policies for a 15-county region near San Francisco. The first, "business as usual," scenario assumes that the development process will continue to be guided by market forces and existing locally based growth policies. The second, "maximum environmental protection," scenario assumes the coordinated adoption of stringent environmental protection policies by all local governments (e.g., prohibiting development on slopes greater than 15 percent, in wetlands or in prime agricultural areas). The third, "compact cities," scenario assumes the county-wide adoption of policies which promote compact and continuous development (e.g., specifying minimal development densities and that 20 percent of all projected growth be directed to developable or redevelopable parcels within the city boundary). A detailed analysis of the results obtained by running these three scenarios and a county-level farmland preservation ordinance is provided in Landis (1995).

SECOND CALIFORNIA URBAN FUTURES MODEL

The second California Urban Futures model, *CUF-2*, was developed by John Landis and his colleagues to overcome some of the limitations of the first CUF model. In particular, it: (1) includes multiple land uses (*CUF-1* considered only residential uses); (2) allows different land uses to "bid" against each other for preferred sites; (3) is calibrated against recent experience; and (4) incorporates a "pseudo-pricing dynamic" into the development spillover process.[iii]

As pointed out above, the *CUF-1* model is vector based and utilizes developable land units (DLUs) that were created by overlaying multiple vector-based GIS layers. *CUF-2*, on the other hand, is raster (or grid cell) based. It uses a grid of nearly 1.8 million one hectare (100m by 100m or approximately 2.47 acre) cells to model nine counties in the San Francisco Bay area. The *CUF-2* model is also conceptually simpler, theoretically richer, and much more data intensive than its predecessor. In particular, it incorporates four submodels that are described briefly below.

Activity Projection Component. The activity projection component of the model consists of a series of econometric models that are used to project future population, households, and employment by jurisdiction at ten year intervals. The equations used to project population and households are that same as those used in the *CUF-1* model. *County Business Pattern* data for 1981, 1989, and 1993 were used to prepare employment projections for thirteen three-digit SIC sectors. Employment estimates were prepared for ZIP code areas and aggregated by city and sector. Separate projection models were developed for each employment sector.

Spatial Database. As was true for the *CUF-1* model, the *CUF-2* spatial database consists of developable land units (DLUs), i.e., potentially developable or redevelopable sites. The *CUF-2* DLU database consists of 100m by 100m grid cells, which may or not be uniquely different from adjacent grid cells. The database consists of the following layers: (1) 1985 and 1995 land uses; (2) percent slope; (3) wetlands; (4) 1990 city boundaries and spheres of influence; (5) urbanization and agricultural land quality; (6) 1990 General plan designation; and (7) major highway and railroad rights-of-way, highway interchange, and railroad stations. The following land use categories are considered in the model: (1) undeveloped; (2) single-family residential; (3) multi-family residential; (4) commercial; (5) industrial; (6) transportation; and (7) public.

Land Use Change Submodel. The land use change submodel is the heart of the *CUF-2* model. It is a series of multi-nominal logit equations that relate observed hectare-scale land use changes between 1985 and 1995 to more than two dozen site and community characteristics. The model projects nine different site-level land use changes: (1) changes from undeveloped to four land uses; (2) changes from three land uses to other uses; and (3) no changes in developed or undeveloped land uses. Separate models for changes in vacant and developed cells were estimated for each of the eight counties.

All of the equations related observed land use changes between 1985 and 1995 to the following independent variables: (1) initial site use; (2) four demand factors including the rate of household and job growth in the previous five years and the number of households and jobs in 1985; (3) accessibility and distance measured as the distance to downtown San Francisco and San Jose and the distance to the nearest highway interchange and BART station; (4) physical and cost constraints including slope and distance to the nearest sphere-of-influence boundary (as a measure of the cost of providing required infrastructure and urban services); (5) policy constraints including whether a site is in a sphere-of-influence boundary or contained prime farmland (current zoning was not considered); (6) adjacent use effects measured as the percentage of surrounding grid cells that are in each urban use; and (7) externality and proximity effects measured as the distance to the nearest commercial, industrial and public use sites. The model calibration results are described in detail in Landis and Zhang (1998b).

Simulation Engine. The results obtained by calibrating the land use change submodel can be used to calculate site specific land use change probabilities, i.e., the probability that a specific vacant or previously developed cell will be developed or redeveloped with a residential, commercial, or industrial use. These probabilities (which can be interpreted as “bid scores”) allow different uses to compete for particular sites. They also allow projected land uses to “spill over” from one use to another (e.g., for unsatisfied residential demand to be allocated to sites whose “highest and best use” is commercial development) and from one jurisdiction to another.

The *CUF-2* model allows alternative land use policy choices to be simulated in four ways. Policies that prohibit particular types of development in particular locations (e.g., policies which prohibit industrial development within one kilometer of an existing freeway) can be simulated by eliminating those sites from the allocation process. Policies that discourage—but do not prohibit—development (e.g., which discourage development outside of a city's sphere of influence) can be simulated by multiplying all of the disadvantaged sites by a fraction, say 0.5. Policies which increase sites' suitability for development, e.g., the construction of a new freeway, can be simulated by locating the proposed freeway in the GIS data set, measuring sites' proximity to the proposed freeway, and recalculating the associated land use change probabilities. And, fourth, policies which limit development in some sites (e.g., from areas with slopes between 10% and 25%) or eliminate it from others (e.g., areas with slopes greater than 25 percent) can be simulated by reducing the development probabilities for some cells and setting others to zero.

The *CUF-2* model has been used to consider two baseline and five alternative policy scenarios for Contra Costa County, California. The first baseline scenario allocated development to only undeveloped sites and imposed minimum development probability thresholds. The second baseline scenario allowed for redevelopment and imposed no minimum development probability thresholds. The first two alternative scenarios looked at the impact of regulating growth to be consistent with local general plans and to protect environmentally sensitive areas. The third and fourth alternative scenarios looked at the impacts of constructing a new limited access highway and adding rail transit capacity. The final scenario investigated the impacts of eliminating cities' ability to limit or encourage development within their borders. The results obtained from these scenarios are described in detail in Landis and Zhang (In press).

A simplified version of the *CUF-2* model, called the California Urban and Biodiversity Analysis (CURBA) has also been developed by Landis and his colleagues (Landis, et al. 1998). Like the *CUF-2* model, CURBA includes two major modeling components (1) an Urban Growth Model which includes procedures for calibrating county-wide equations describing past urbanization patterns and using those equations to define future development scores; and (2) a Policy Simulation and Evaluation Model which provides procedures for simulating how alternative growth policies might affect future urbanization patterns. The Urban Growth Model uses GIS data but is calibrated outside of a GIS environment using procedures similar to the *CUF-2* model. The Policy Simulation and Evaluation Model is embedded in ArcView and uses ArcView's Spatial Analyst extension and specially-written Avenue scripts to develop and display the outputs for alternate growth scenarios.

PORTAGE COUNTY MODEL

The Portage County Model was developed by Jay Lee and his colleagues to allow private citizens and elected officials to observe the implications of implementing different strategies for managing residential growth in Portage

County, Ohio.[iv] The model is GIS-based and custom designed to incorporate the GIS data that were available for Portage County. These data included: (1) generalized land use in thirteen categories for three years, 1977, 1987, and 1995; (2) farmlands; (3) generalized zoning districts; (4) water- and sanitary sewer-service areas; (5) critical natural areas created by combining information on floodplains, wetlands, natural heritage areas, and ground-water pollution potential; (6) surface water; (7) roads; and (8) population projections for each city, village or township in the county.

The GIS data were combined with information on residential building permits and land subdivision data to generate maps showing the County's development patterns for the last 20 years. The population forecasts and information on current development trends were then used to develop three development simulation models that projected alternative residential development patterns for the period between 1995 and 2015. The models were:

Continued Growth Model. The base line, "continued growth," model demonstrated what would happen if current trends, growth policies and zoning regulations were continued and the County's population grew by 27,000 between 1995 and 2015. The model assumed that: (1) half of all new residential development would occur in the incorporated areas of the county and half would occur in unincorporated areas; (2) 80% of new development in unincorporated areas will be located along existing street frontages and 20% will be located in conventional platted subdivisions; (3) residential development will occur at densities that are consistent with existing zoning; (4) no changes will be made in local development policies, zoning, and subdivision regulations; (5) development would continue to be permitted in environmentally sensitive areas; and (6) water and sanitary sewer services will be provided beyond current service areas.

Managed Growth Model. This scenario demonstrates how much land would be lost if growth management tools and incentives were adopted by all local governments in the county and the County's population grew by 27,000 between 1995 and 2015. The model assumed that: (1) half of all new residential development would occur in the incorporated areas of the county and half would occur in unincorporated areas; (2) 35% of new development in unincorporated areas will be located along existing street frontages, 35% will be located in conventional platted subdivisions, and 30% will be located in conservation subdivisions which preserve at least one-half of the subdivision as protected open space; (3) all communities adopt zoning policies which prohibit residential development in environmentally sensitive areas; (4) all communities adopt policies to encourage redevelopment and in-fill at higher densities than in the continued growth model; and (5) necessary sanitary sewer capacity will be provided in existing sewer-service areas.

Controlled Growth Model. This scenario demonstrates how much land would be lost if more aggressive growth management strategies were adopted by all local governments in the county and the County's population grew by 20,000 (i.e., 7,000 less than in the other two scenarios). The model assumed that: (1) 60% of all new residential development would occur in the incorporated areas of the county and in township growth centers which locate all residential development within one-half mile of a mixed-use village center; (2) 25% of the growth in unincorporated areas will be located in growth centers, 40% will be located in conservation subdivisions, 17% will be located along existing street frontages, and 17% will be located in conventional platted subdivisions; (3) all communities adopt zoning policies which prohibit residential development in environmentally sensitive areas; (4) all communities adopt policies to encourage redevelopment and in-fill at higher densities than in the managed growth model; and (6) necessary sanitary sewer capacity will be provided in existing sewer-service areas and in the township growth centers.

The simulations were prepared by dividing the county into 30 meter x 30 meter grid cells and identifying all cells that are currently undeveloped and zoned for residential development. The simulations are guided by the projected demand for dwelling units and the assumptions for each model described above. A simulation first looks for developable land in current or proposed water- and sewer-service areas. If no suitable sites are found, a random number generator is used to identify developable vacant and farmland cells which are assumed to be redeveloped. In the controlled growth model, the simulation tries to limit the random cells to locations closest to a specified growth center. In the managed and controlled growth scenarios, the simulation develops vacant land before farm land. The simulation continues selecting and “developing” cells until the projected residential growth for each community is accommodated.

The model was used to generate maps showing the residential development patterns which would occur under each simulation model. Summary information was also generated on the amount of land that would be converted to residential uses, removed from farm production, and lost from critical natural areas. Not surprisingly, the continued growth model produced the most scattered residential development pattern and consumed the most agricultural and environmentally sensitive land. The implementation of moderate growth management strategies under the managed growth model resulted in a more compact development pattern and the loss of less agricultural and sensitive land. The implementation of more aggressive growth-management strategies in the controlled growth scenario, combined with regional efforts to decrease migration from older urban centers, generated even more compact, and efficient land development patterns.

In its second phase that was completed in October 1999, Portage County model was extended to also simulating commercial and industrial land uses. Similar approaches to the simulations of residential land use, the Portage County model receives from planners and local communities the projected growth estimates as inputs for its simulation processes. Results of the simulations suggested possible scenarios of growth patterns under another set of three alternatives: (1) the continued growth scenario, (2) the managed growth scenario, and (3) the environmentally conservative growth scenario. While the continued growth scenario and the managed growth scenario are similar to those of the first phase in the Portage County model, the environmentally conservative growth scenario seeks to actively avoid developing lands in environmentally sensitive areas.

WHAT IF?

What if? has been developed by Richard Klosterman and his partners in the Plan it!, LLC.[v] As its name suggests, What if? is an explicitly policy-oriented planning tool that can be used to determine *what* would happen *if* clearly defined policy choices are made and assumptions concerning the future prove to be correct. Policy choices that can be considered in the model include the staged expansion of public infrastructure and the implementation of alternative land use plans or zoning ordinances. Assumptions for the future that can be considered in the model include different population and employment trends, assumed household characteristics, and anticipated development densities.

What if? projects future land use patterns by balancing the supply of, and demand for, land suitable for different uses at different locations. It does this by providing three integrated model components: (1) a suitability option for developing land suitability scenarios which determine the supply of land; (2) a growth option for creating growth scenarios which determine the demand for land; and (3) an allocation option that projects future land use patterns by allocating the projected land use demands to the most suitable sites. Alternative visions for an area's future can be explored by defining alternative suitability, growth, and allocation scenarios. These three options are described briefly below.

Suitability Option. *What if?*'s suitability option incorporates standard "weighting and rating" land suitability analysis procedures (McHarg 1969; Hopkins 1977) in a quick and easy computer-based process. The suitability analysis process begins by using on-screen forms to modify a previously defined suitability scenario or create a new one. The suitability scenario assumptions are then entered on a form containing four tabbed sheets. The first sheet contains check boxes which are used to specify the factors (e.g., slopes, soils, and hazardous areas) which the user feels should be considered in determining the suitability of different locations for each land use. The second sheet is used to specify the suitability factor weights, i.e., numerical scores indicating the relative importance of different factors for determining the relative suitability of different locations for each land use. The third sheet is used to specify ratings for each suitability factor type, i.e., numerical values which indicate the relative suitability of locations with different factor types (e.g., different slopes) for locating a particular land use. The fourth sheet is used to specify land uses that may be converted from their current use (e.g., agriculture) to another use (e.g., low-density residential) as a result of the projection process.

After all of the required information has been entered for all land uses, the model computes the factor scores for all locations in the study area by multiplying the user-specified factor weights by the corresponding user-defined factor rating and summing these values. The system then generates a series of maps showing the relative suitability of different locations for each land use. It also generates two reports. One report records the number of acres within each suitability class for all land uses. The second lists the assumptions which underlie a particular suitability scenario.

Demand Option. *What if?* considers the demand for land by converting the five main categories of land use demand—residential, industrial, commercial, preservation, and locally-oriented uses—into the equivalent future land use demands. The demands are computed for up to five periods, allowing the system to incorporate a staged development process in which future development patterns are based on the previously existing development patterns and anticipated infrastructure improvements.

The process of projecting land use demands begins by selecting a growth scenario to view, modify, or create. The user is then presented with a form containing five subsidiary sheets which are used to specify the assumptions which define the demand for different land use demands. For example, the Residential sheet contains two tabbed sheets. The first sheet allows the user to select between up to five independently prepared projections for the total number of households in the region and the study area's share of the regional households. The second sheet is used to specify assumptions about new residential units including: the breakdown by housing type for new residential construction, the housing density for each housing type, and the average household size for each housing type. After all of the required information has been provided, the system computes the associated demand for each land use. It then generates reports which identify the projected demand for each land use in each projection year and list the assumed values that were used to determine these demands.

Allocation Option. *What if?* projects future land use patterns by allocating the projected land use demands—derived from a user-selected growth scenario—to different locations on the basis of their relative suitability—as defined by the assumptions of a user-selected suitability scenario. For instance, the projected demand for residential land is assigned first to the most suitable sites, then to the second most suitable sites, and so on until all of the residential demand in a projection year has been satisfied. If desired, the growth allocation can be controlled by user-selected land use controls (land use plans and zoning restrictions) and infrastructure plans. The user is notified if not enough land is available to satisfy the projected demand. If this occurs, the user must modify the suitability, growth, or allocation scenario assumptions (e.g., relax land suitability requirements, allow more land uses to be converted to other uses, or increase development densities) to make them consistent.

The projected land use patterns for each projection year can then can be viewed in map or report form. The allocation map shows the projected land uses in each projection period for a given set of suitability, growth, and allocation assumptions. The reports record the projected land use quantities for the study area and each political subdivision in each projection year and the assumptions which underlie a scenario.

While incorporating many of the concepts of other GIS-based models such as the first California Urban Futures model (Landis 1994; Landis 1995), *What* *if?* is unique in providing a setup program which adapts the program to the particular land uses, suitability factors, GIS data sets, and policy concerns for a given study area. The only GIS layer that is absolutely essential for using *What if?* is the existing land uses. A variety of additional layers can be added, depending on the available GIS data, the use's analysis and policy needs, and the requirements of any secondary applications that will utilize the *What if* outputs.

What if? was developed with Microsoft's Visual Basic and the Environmental Sciences Research Institute's (ESRI) MapObjects GIS component software. The model is fully operational and documented and was used to prepare the Western Hamilton Collaborative Plan for a rapidly developing area on the western edge of Cincinnati, Ohio.

SMARTPLACES

The Electric Power Research Institute's *SmartPlaces E* series software integrates decision models with spatial analysis.[vi] *SmartPlaces* is a geographic support system that is used to evaluate the implications and opportunities of plan alternatives or land use choices. It allows users to design and evaluate land use development scenarios with user-selected criteria and priorities. *SmartPlaces* is an open software system which permits the user to define the issues, indicators, evaluation measures, criterion importance, the locations to be considered, and the method to be used in presenting the results.

SmartPlaces applications include: land use planning, transportation systems evaluation, environmental remediation and protection, water allocation, energy forecasting, and disaster evaluation. The system uses ESRI's ArcView GIS and customized *SmartPlaces* extensions. A copy of the *SmartPlaces* User Manual can be downloaded form the *SmartPlaces* Web site. The software provides a set of tools for the exploration, design, modification and evaluation of a geographic based scenario or strategy. The territory or boundaries of the strategy are defined, the characteristics of the target area are identified, and the choices for analysis and evaluation are selected. The outcomes of each strategic choice are reported in both text format and graphic charts.

The *SmartPlaces* package includes the following components:

Scenario Builder. The Scenario Builder is a highly customized ArcView "view" document which displays a one-mile square urban region. It provides the geographic palette upon which land use alternatives are created and edited. It enables users to look at the geographic layout of an area and provides the ability to calculate a scenario's characteristics.

The Scenario Builder contains "editable" and "non-editable" themes or coverages of graphic and database information. "Non-editable" themes include reference data, such as scanned aerial photos, that can not be changed by the user. Working with the "editable" themes, the user can customize the scenario by changing the scenario data and attributes (e.g., development densities), adding features (e.g., a road or a new residential neighborhood), and defining user restrictions for the analysis. The scenario design will almost always be governed by a number of restrictions or policy choices. These may be physical, jurisdictional or simply user-selected design limits (e.g., the maximum number of units per acre). Scenarios are packaged data sets permitting simple storage and retrieval of each set according to chronological, physical, logical or political criteria.

Analysis Model Selection/Scenario Assessment. Once the geographic choices are completed in the Scenario Builder (i.e., the land uses have been described with feature locations, attributes have been defined, and restrictions have been applied), the scenario can then be evaluated. Scenario assessment is performed by launching analysis models using the *SmartPlaces* Radix evaluation tool. The Radix evaluation tool allows the design choices to be assessed for their impacts on the community. The Radix framework provides numerical and visual answers to the what-if questions posed by the scenario.

A Radix is made up of a hierarchy with three levels: (1) a core, (2) features or evaluation topics, and (3) indicators or evaluation models. The Radix is constructed by: (1) defining a central core issue; (2) identifying analysis features or topics (such as land use, energy, water, environment or transportation) and (3) connecting an indicator (math function or separate model). Each of the core-feature-model links is called a chain. *SmartPlaces* permits any number of Radixes to be used with as many chains in each Radix as desired for scenario evaluation. Analyses are grouped into categories by feature or topic and are connected to an analysis model which are run to evaluate the scenario.

For example, a Radix can be designed to evaluate the total land area in acres occupied by residential land uses in the Scenario. In this example, the core of the Radix would be Resources with a view toward understanding that an existing community needs to support new development within its boundaries. The feature to be evaluated would be Land Use. The indicator would be Residential Acres, calculated as the sum of acres for all residential components in the Scenario.

The Radix structure is completely customizable and additional analysis models can be connected. The analysis or evaluation models can

1. process spatial and tabular data associated with themes in the Scenario Builder;
2. process external databases; or
3. link to autonomous external models.

In one application of *SmartPlaces*, an emissions prediction model was linked to evaluate land use scenarios in terms of carbon monoxide, carbon dioxide and sulfurous gas emissions. A short on-line tutorial that covers the development and application of a simple scenario-radix evaluation can be found on the *SmartPlaces* Web site.

The *SmartPlaces* Compliance Checking feature can be used to see if scenarios comply with numeric targets, such as development ordinances and/or spatial restrictions (e.g., floodplains). Once the analysis model execution is complete, results are presented in a summary table and can be displayed graphically in a variety of formats. *SmartPlaces* allows users to save and retrieve land use scenarios and create several alternative scenarios.

TRANUS

TRANUS is an integrated land use and transportation model which can be applied at a community or regional scale. The integrated modeling package provides users with a means for projecting medium- and long-term transportation demand and assessing the implications of alternate transportation policies on the location of and interaction between activities. The program can be used to: (1) simulate the probable effects of applying particular land use and transportation policies and programs; and (2) evaluating the associated effects from social, economic, financial and energy points of view. The *TRANUS* system has been developed by Modelistica, a Venezuelan company, since 1982.[vii] The system runs on a PC and has a GIS interface. A sample application of *TRANUS* can be downloaded from Modelistica's Web site.

TRANUS is based heavily on the work on Domencich and McFadden (1975) which uses discrete choice analysis and random utility theory to deal with the problem of transport modal choice. This theoretical backbone has been extended in *TRANUS* to all decision levels, from modal split to assignment, trip generation, and the location of activities. A detailed explanation of the theory underlying the *TRANUS* system can be found in de la Barra (1989).

The *TRANUS* modeling system is very flexible, and can be applied to a large variety of case studies, ranging from very simple urban or regional models, to highly sophisticated ones. The model user defines the number of variables to include and, as a result, the system's data requirements vary accordingly.

The land use model is a spatial input-output model or activity location model. A typical application includes employment, population, and land uses. The study area must be divided into zones and the economy of the area must be divided into sectors. To calibrate the model, the number of jobs by sector and zone must be known for at least the base year. Similarly the number of households or population by type must be given in each zone. In the case of land, not only the quantities of land per type and zone are needed, but also an indication of prices and a description of current land use policy. A good land use map, preferably in GIS form, is particularly useful. As a result of the activity location process, a set of matrices of flows is produced from which potential transportation demand may be derived.

On the transportation side, a conventional definition of the physical network is required. Each link must be defined in terms of distances, capacities, link-types, free-flow speeds, and other characteristics. The purpose of the transportation model is to transform potential demand into actual trips, determine modal splits, and assign the demand to different transportation system options based on their capacity restrictions. Classified traffic counts, transit ridership, and traffic speeds and the results of stated preference surveys and revealed preferences data are convenient sources of model calibration information. A travel survey is enough to calibrate the model and estimate demand because *TRANUS* can also use available information about population, employment and land use. *TRANUS* can also be integrated with other transportation modeling packages, such as EMME/2, TRIPS, MiniUTP, Tranplan or TransCAD.

TRANUS can be used to simulate and evaluate land use and transportation policies by preparing a projection for a base case scenario, in which the policies are not included, and an alternative scenario which includes an explicit definition of the policies. The differences in the results will represent the net effect of introducing the policies. The evaluation procedure compares the results of the base case and alternative scenarios, and estimates a number of socio-economic, financial, and optionally, energy consumption indicators.

In one application (Johnson and de la Barra 1998), Robert Johnson and his colleagues at the University of California, San Diego, used the results of the land use simulations from *TRANUS* as a basis for further modeling. Zone-based forecasts for population, employment, and land use obtained from *TRANUS* were then disaggregated to polygons. This was done by applying GIS procedures such as calculating each polygon's proximity to a highway interchange or to parks and recreation facilities. The *CUF-1* model was then used to assess the environmental impacts of the land use and transportation policy alternatives.

URBANSIM MODEL

The ***UrbanSim*** model is available from http://www.urbansim.org where Paul Waddell and his team at the University of Washington have been developing and implementing a model to simulate the interaction of many actors making decisions within the urban market for land, housing, non-residential space and transportation.

Running the *UrbanSim* model requires exogenous input information derived from:

- Population and employment estimates
- Regional economic forecasts
- Transportation system plans
- Land use plans
- Land development policies such as density constraints, environmental constraints, and development impact fees

The users of the *UrbanSim* model creates *scenarios* by interacting with the system. Users specify alternative packages of forecasts, land use policy assumptions, and other exogenous inputs. The model is then executed for a given scenario, and the results of one or more scenarios can be examined and compared in the GIS viewer component of the user interface.

The *UrbanSim* model has two key components: (1) ***Demographic module*** and (2) ***Economic transition module***. It works at regional level, consistent with exogenous aggregate forecasts of population and employment. The model then predicts the location of businesses and households, the location, type, and quantity of new construction and redevelopment by developers, and the prices of land and buildings.

For household mobility and location, the *UrbanSim* model simulates household decisions about whether to move or remain in their current residence, and if they choose to move, their selection of a housing type and zone. For the business mobility and location, businesses make similar choices regarding mobility, building type and location choice. Household and business characteristics influence choices, as do locational attributes such as accessibility and prices.

For the land development, the *UrbanSim* model simulates developer choices to convert vacant or developed land to urban uses, including the type of improvements and density, based on their profitability expectations and subject to constraints imposed by governmental policies such as zoning and infrastructure availability. These profitability expectations are influenced by prior prices and revealed demand in the location and building type preferences of businesses and households.

The *UrbanSim* model may be structured to produce simulated results at a disaggregated level. Its output information include:

- Future year distributions of population
- Households by type (e.g. income, age of head, household size, presence of children, and housing type)
- Businesses by type (e.g. industry and number of employees)
- Land use by type (user-specified)
- Units of housing by type
- Square footage of nonresidential space by type
- Densities of development by type of land use
- Prices of land and improvements by land use.

While the *UrbanSim* model takes a behavioral approach to capture complex interactions in the markets for land, development, and transportation, it is inevitable that the factors being considered are more than other models being reviewed here. As it is able to disaggregate locational information in its simulations and thereby increasing its complexity for the public to comprehend without proper training in planning or public policy research, the *UrbanSim* model may not be suitable for the EMPACT project that is actively avoiding complex theoretical treatment of the issues. However, the availability of a sample project and its associate software (with source code) from the home page of the *UrbanSim* model is a plus for those who wish to further develop simulations by taking similar approaches as those of the *UrbanSim* model.

MEDINA COUNTY MODEL

The final model is currently being developed for Medina County, Ohio, by Chengri Ding and his associates.[viii] The model is a grid (or raster) GIS-based model similar in many respects to the *CUF-2* model in using past development patterns for each grid cell to project future growth patterns. The analysis is done for one-half hectare meter square grids and only considers conversions from agricultural or “vacant” land to residential land uses. The model attempts to analyze trends in urban residential land development, forecast future urban residential development patterns, and examine the impacts which land use and development control policies will have on future residential patterns.

The model utilizes a multiple-regression equation to project current and future residential development patterns in each cell as a function of: (1) locational variables including the distance to the regional CBDs, regional transportation networks, and major employment centers; (2) structural variables including the presence of transportation facilities, job opportunities, and currently urbanized land; and (3) neighborhood variables including the amount of developed land in adjacent cells.

The analysis indicates that the extent to which adjacent cells are currently developed has the largest impact on the cells' development patterns. Unfortunately this variable cannot be used to project future development patterns because it assumes that one knows what is being forecasted. That is, if the future state of a cell is dependent on the concurrent state of adjacent cells, one can only forecast the future state for a particular cell if one knows the future state of adjacent cells, i.e., what one is attempting to forecast. As a result, while the current model is useful for explaining current urban development patterns, it must be revised substantially before it can be used for projection purposes.

MODEL EVALUATION

Cost

Given the limited budget for developing the Northeast Ohio Fifteen-county EMPACT model, the costs of purchasing, developing, and installing the model (or models) to be used in the project is inevitably the most important consideration. A model that is highly desirable on all the other criteria but is too expensive or difficult to set up must, by necessity, be eliminated from consideration. This, of course, does not imply that the model is not appropriate for other applications or could not be used in future modeling efforts, if additional funds were made available.

Although it is difficult to obtain firm cost information on some of the models, the following conclusions can be drawn on each of the models considered in this review:

- ***METROPILUS***. This model is clearly too expensive to be implemented within the current project. The model can only be purchased as part of a comprehensive consulting package that includes the custom installation and calibration of the model. Although the costs of this vary widely depending on the size of the analysis area and the desired model outputs, the cost of installing the model is well over $100,000, well outside of the EMPACT modeling budget.
- ***CUF-1***. The first California Urban Futures Model is not a commercial package and thus no funds would be required to purchase the package.

However, it was custom designed to work with particularly rich data sets that are available for the northern California area. It was also custom designed to work only on particular computers located at the University of California, Berkeley, running customized ARC/INFO macros. As a result, while the concepts that underlie the CUF-1 model are readily accessible, it would be extremely difficult, if not impossible, to implement that model in northeast Ohio.

- ***CUF-2***. The second California Urban Futures Model is also a noncommercial package that was custom designed to work with the unique GIS data sets that are available in California. It was also designed only to work with particular computer equipment and software. However, the CURBA model (Landis, et al. 1998) utilizes ESRI's ArcView and Spatial Analyst software and Avenue scripts that can be obtained at no cost from the system developers. As a result, while it would be difficult, if not impossible, to implement the *CUF-2* model, it might be possible to develop a more limited version based on the CURBA model.
- ***Portage County Model***. The Portage County model is a noncommercial package that was developed by Jay Lee and his colleagues at Kent State University. As a result, these resources are readily available, making it feasible—both financially and technically—to implement the model for other areas within Northeast Ohio.
- ***What if?***. The *What if?* package is a commercial software package that has been designed to work with any set of available GIS data. While

the package's normal licensing fee is outside the EMPACT modeling budget, special arrangements may be made to use the software on a limited, demonstration, basis. Since the package is designed to be adapted to any GIS data set, it would also be technically feasible to use the model in the EMPACT modeling effort if special arrangements could be made for reduction of cost.

- ***SmartPlaces***. *SmartPlaces* is distributed by the Electric Power Research Institute (EPRI) at no cost to EPRI members. Unfortunately the cost of obtaining a copy of the software for use in northeast Ohio is outside of the EMPACT modeling budget, making it impossible to use this package within the current modeling effort.
- ***TRANUS***. The *TRANUS* model is another commercial package whose costs lie well outside the EMPACT modeling budget. As a result, it is not possible to use this package as part of the current modeling effort.
- ***UrbanSim*** Model. The UrbanSim model may be downloaded from its home pages. The source code, executive code and a sample project zipped file are available. While it requires users to register when downloading the software and related modules, it is free and readily accessible.
- ***Medina County Model***. The Medina County model is similar to the Portage County model in that it was constructed by an academic team, primarily for research purposes. As a result, there is no need to purchase a commercial package. However, the current Medina County model

cannot be used for projection purposes and must be modified for this purpose. The costs of making these modifications may be substantial and may not be covered within the current EMPACT budget.

ABILITY TO WORK WITH AVAILABLE DATA

From the practical standpoint of actually implementing a model (or models), the issue of whether the required data are—or will be—available for the EMPACT modeling is second only to the issue of the model's cost. As a result, this issue is essential for selecting the model(s) to be used in the EMPACT modeling effort. Although it is difficult to obtain this information for all of the of the models, the following conclusions can be drawn on each of the models considered in this review:

- ***METROPILUS***. This model has very substantial data requirements which can be one of the reasons why it can only be purchased as part of a comprehensive consulting package. This reaffirms the conclusion that this model cannot be used as part of the current EMPACT modeling effort.
- ***CUF-1***. As was pointed out above, the first California Urban Futures Model was custom designed to work with particularly rich data sets that were available for the northern California area. These data include: (1) TIGER/Line data on roads, census tracts, city boundaries and the like; (2) slopes; (3) highway and urbanized area buffers; (4) prime agricultural land; (5) marsh and wetlands; and (6) sewer and water utility service costs

(approximated by the straight line distance to the nearest already-developed area). Some of these data are available for some of the counties in the fifteen-county region. However, only the TIGER/Line data are available for the entire study region, making it impossible to implement the model for the entire study area.

- ***CUF-2***. The second California Urban Futures Model was also custom designed to work with the unique GIS data sets that are available in California. The data required to use the model are: (1) land use at two points in time for all locations in the study area; (2) the rate of household and job growth for the previous five years for all cities; (3) distance to the nearest urban center; (4) slopes; (5) wetlands; (6) distance to the nearest sphere of influence boundary (as a proxy measure for the cost of providing required infrastructure and urban services; (7) location relative to (i.e., inside or out of) designated municipal spheres of influence; (8) prime farmlands; (9) adjacent land uses; and (10) distance to the nearest commercial, industrial, and public use site. Most, but not all, of these variables can be obtained—with some difficulty—for much of the fifteen-county study area.
- ***Portage County Model***. The Portage County model used a great deal of information that was available for Portage County including: (1) general land use at three points in time; (2) farmlands; (3) generalized zoning districts; (4) water-and sewer-service areas; (5) critical natural areas that were identified by combining information on slopes, floodplains, wetlands, natural heritage areas, and ground-water pollution potential; (6) TIGER/Line information on

roads and surface water; and (7) the projected population for all cities, villages, and townships. Most, but not all, of these data are available for the fifteen-county study area. Successful implementation of this model in the 15-county region of Northeast Ohio will depend on the availability of the data layers needed in the models.

- ***What if?***. The *What if?* package is a commercial software package that has been designed to work with any set of available GIS data. The only required GIS layer is the existing land uses. However, a variety of additional layers can be added, depending on the available GIS data and the user's analysis and policy needs. It is highly desirable to include at least three natural features layers for the Suitability analysis and two or three layers for the Allocation analysis. Some basic boundary and display layers are highly desirable. All of these data are available for portions, but not all, of the study area.
- ***SmartPlaces***. *SmartPlaces* can be customized to work with a variety of data sets including: (1) TIGER/Line files for roads, streets and other features (rail, airport, hydrology etc) ; (2) AutoCAD files showing topology, facilities and land use characteristics; (3) scanned aerial photos; (4) Census and specialized spatial data sets; and (5) other information which may be available on land uses, population, housing, employment, communications, energy consumption. Some, but not all, of these data are available for portions of the fifteen-county study area.

- ***TRANUS***. The *TRANUS* model has extensive data requirements including: (1) information on the current employment, population, and land use for transportation analysis zones (TAZs); (2) current land use and price; (3) a complete description of the transportation network including capacities, distances, link types, free flow speeds, operating and maintenance costs, traffic counts, transit ridership, and the results of a travel survey. None of these data are available for even portions of the fifteen-county region.
- ***UrbanSim*** Model. The *UrbanSim* model is currently structured specifically for the sample project and its databases. To customize it for the 15-county region in Northeast Ohio, the computer code will have to be re-developed or modified. The required data for housing prices and other transportation information are not all available for the fifteen-county region.
- ***Medina County Model***. The current version of the Medina County model has rather extensive data requirements including: (1) land uses at two points in time; (2) trip generation data for TAZs (traffic analysis zones); and (3) current zoning. These data are available for portions, but not all, of the fifteen-county region.

OUTCOMES VIEWABLE VIA THE WEB

A stated goal of the EMPACT fifteen-county modeling effort is developing a model that will allow public officials, private citizens, and interest group representatives to view the impacts of different policy choices via the World

Wide Web. None of the models considered above provide this capability. In addition, legal and practical difficulties make it impossible to modify six of the models to operate over the Web. Five of the commercial packages, *METROPILUS*, *SmartPlaces*, *INDEX*, *TRANUS* and *UrbanSim*, are written in copyrighted code that cannot be modified within the scope of this project. The *CUF-1* and *CUF-2* models have been developed using customized hardware and software that is only available at the University of California, Berkeley, making it impossible to develop Web-enabled versions of these models.

Fortunately, it may be possible to develop Web versions of the remaining packages. *What if?* is written in Visual Basic which could be modified to run over the Web. It would also be possible to modify the Portage County and Median County models so that selected model results can be stored and displayed via the Web. It may also be possible to develop a version of the CURBA model that could operate over the Web.

Understandability of Model Assumptions and Operations

It is highly desirable that any model that is used to inform public debate be understandable, at least in its general outline, by people who are not technically and quantitatively sophisticated. This is important because the general public will naturally be distrustful of "black box" models whose underlying assumptions and operations they cannot understand. Although it is difficult to compare the "understandability" of this diverse set of models precisely, a rough ordering (from most understandable to least understandable) would be as follows:

1. Portage County Model
2. *CUF-1*
3. *What if?*
4. *SmartPlaces*
5. *CUF-2*
6. Medina County Model
7. *TRANUS*

8. *METROPILUS, and*
9. *UrbanSim.*

Theoretical Soundness

A model's theoretical soundness is, almost inevitably, inversely related to its understandability. That is, given the complexity of actual urban development processes, models which do a better job of capturing this complexity will naturally be more complex—and difficult to understand—than less complex models. While it is difficult to directly compare one model's "theoretical soundness" to another's, the models considered in this review can be ordered in the following way (from the most theoretically sound to the least theoretically sound):

1. *METROPILUS*
2. *TRANUS*
3. *UrbanSim*
4. *CUF-2*
5. *CUF-1*
6. *What if?*
7. Portage County Model
8. *SmartPlaces*
9. Medina County model (as currently specified).

RECOMMENDATIONS

The model(s) to be used in the fifteen-county EMPACT study must be able to operate at both the regional (fifteen-county) and sub-regional (county and sub-county) levels. In addition, it (or they) must be able to project future land use patterns that reflect the implications of adopting alternative growth management strategies and allow the user to determine the implications of alternative policy choices via the Web.

The process of recommending the model(s) to be used for the EMPACT fifteen-county modeling project must begin by eliminating from consideration models which are clearly outside the budget of the current project. As pointed out above, these models include: (1) the *METROPILUS* model developed by Steven Putman and his associates; (2) *SmartPlaces*; (3) *INDEX*; and (4) *TRANUS*. The following additional models can also be eliminated from consideration due to the practical difficulties of converting "one off" models that were developed for particular hardware and data configurations to work in northeast Ohio: (1) *CUF-1*; and (2) *CUF-2*. That leaves the following models for further consideration:

- Portage County Model;
- *What if*, and
- Medina County Model

Given the project's ambitious goals and the vast differences in the kinds of data that are available for different portions of the fifteen-county region, it is clear that none of these models can be used at both the regional (i.e., multicounty) and sub-regional (i.e., county or sub-county) levels. As a result, the real question is which model (or models) is(are) best suited for the regional-scale analysis and which is(are) best suited for sub-regional analyses.

The Portage County model and the *What if?* model are both appropriate for sub-regional analyses. In fact, they are equivalent models in many ways. They are both GIS-based models that draw heavily on the first California Urban Model (*CUF-1*). As a result, their underlying operations are very similar, as are their data requirements:

- both the Portage County model and the What if? Model have been designed to be adaptable to any study area and GIS data set;
- the Portage County model deals only with residential, commercial and industrial land uses while the *What if?* model deals with as many land uses as are appropriate for a particular study area;
- the land use allocation procedure in the Portage County model is an explicitly random process while the *What if?* land use allocations are based on the results of a land use suitability analysis that is part of the modeling process;
- the *What if?* model and the simulation portion of the Portage County model have been written with Visual Basic programming language which allows them to be directly adapted for use over the Web.

While the *What if?* model can be modified to run over the Web and used to prepare sub-regional models for counties in which the required GIS and other data are available, there is still issues of private ownership of the computer code and proprietary database. It is recommended that the Portage County model be modified to provide an example for sub-regional growth model in the 15-county regions of Northeast Ohio. The growth scenarios in the Portage County model can be modified to meet different local conditions or different local requirements. We recommend that the Portage County model be modified so that the computer programs are made publicly available.

It is further recommended that the Medina County model be expanded for use in preparing analyses for the fifteen-county area. It is further recommended that the current Medina County model be modified to incorporate features of the structurally similar *CUF-2* and *CURBA* models to the extent possible.

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NOTES

[i]. The following discussion of the METROPLIS model and its *DRAM*, *EMPAL*, and *LANDCON* components is based on Putman (1995).

[ii]. The following discussion of the first California Urban Futures Model draws heavily on Landis (1994) and Landis (1995).

[iii]. The following discussion of the second California Urban Futures model is based on Landis and Zhang (1998a); Landis and Zhang (1998b); and Landis and Zhang (In press).

[iv]. The following discussion of the Portage County model is based on Lee et al. (1998).

[v]. The following discussion of the What if? PSS is based on Klosterman (1999).

[vi]. The following discussion of the SmartPlaces model is based on information from its Internet web site. <http://www.smartplaces.com>.

[vii]. The following discussion of the TRANUS model is based on information from the Modelistica Web site <http://www.modelistica.com>.

[viii] The following discussion of the Medina County model is based on Ding et al. (1999).