Analytical Tools for Land Use, Transportation, and Growth Management

Paul Waddell
Department of Urban Design and Planning and
Daniel J. Evans School of Public Affairs
University of Washington
Box 353055
Seattle, WA 98195
pwaddell@u.washington.edu

Paul Waddell is an Associate Professor at the University of Washington, Department of Urban Design and Planning and Daniel J. Evans School of Public Affairs, and Director of the Interdisciplinary PhD Program in Urban Design and Planning. His research focuses on land use and transportation planning, metropolitan development, and urban simulation.

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Abstract

Metropolitan areas have come under intense pressure to respond to federal mandates to link land use, transportation, and environmental quality; as well as to local pressures to manage the side effects of growth such as sprawl, congestion, housing affordability, and loss of open space. Addressing these questions systematically requires analytical tools that integrate land use and transportation. The models used by Metropolitan Planning Organizations (MPOs) were not designed to address these questions. UrbanSim is a new model system that has been developed to respond to these emerging requirements, and has now been successfully implemented and applied in three states.

Introduction

The relationships between land use, transportation, and the environment are at the heart of growth management. The emerging consensus that construction of new suburban highways induces additional travel, vehicle emissions, and land development, making it implausible to 'build our way out' of congestion, has reshaped the policy context for metropolitan transportation planning (Downs, 1992). Recognizing the effects of transportation on land use and the environment, the Clean Air Act Amendments of 1990, the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) mandated that MPOs integrate metropolitan land use and transportation planning, and led to subsequent legal challenges to the traditional approach to transportation planning that ignore these effects (Garret and Wachs, 1996). The passage of the Transportation Equity Act for the 21st Century (TEA21) in 1998, as the successor to ISTEA, softened these planning requirements somewhat, but significant pressure remains to better coordinate metropolitan planning of land use, transportation, and the environment.

Many government agencies, including the U.S. Department of Transportation, the Environmental Protection Agency, and various state and local planning departments began to develop new models, which recognized the link between transportation and land use. Efforts such as the Oregon Department of Transportation's Transportation and Land Use Model Integration Project (TLUMIP), the State of Utah's Quality Growth Enhancement Tools (QGET) and Envision Utah efforts, and the Oahu Metropolitan Planning Organization's investments in new land use and transportation models, are leading the way.

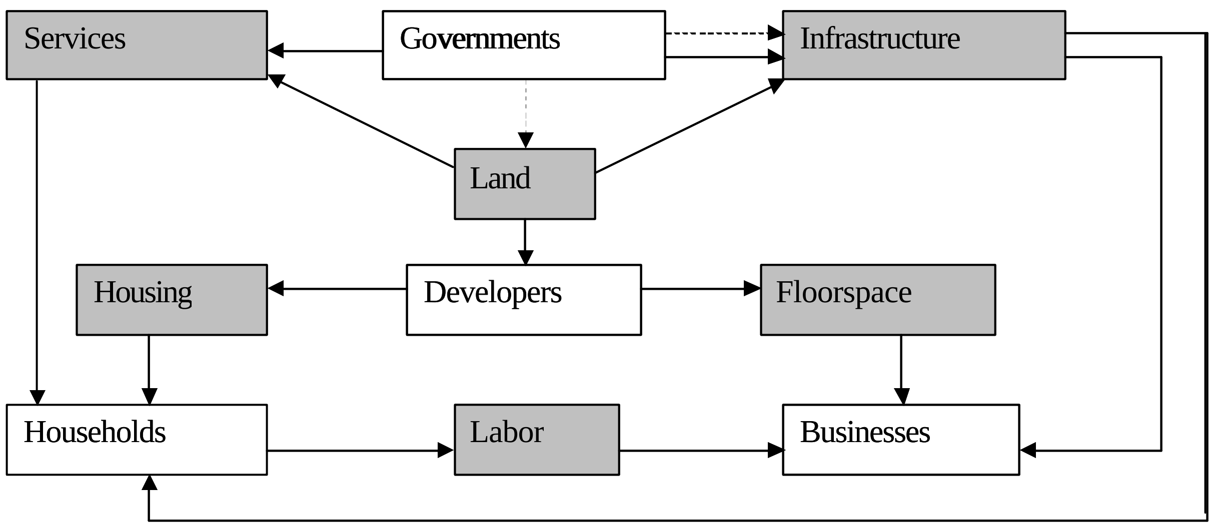
Within the Oregon growth management context, the Oregon Department of Transportation launched an ambitious effort in 1996 to develop enhanced analytical tools to evaluate the interactions between transportation and land use. The TLUMIP effort had two components. The first was the implementation of a statewide land use and transportation model, for which the TRANUS model (de la Barra, 1989) was adopted. The second component of TLUMIP was the development of UrbanSim, a new metropolitan-scale land use model for integration with transportation models. UrbanSim was designed specifically to address the policy analysis requirements of metropolitan growth management, with particular emphasis on land use and transportation interactions.

The Oregon TLUMIP effort extended the original UrbanSim design and applied a prototype version to the Eugene-Springfield metropolitan area. Testing of the current version of the model in the Eugene-Springfield area over a historical period from 1980 to 1994 has provided a robust historical validation of the model. UrbanSim has since been applied in Honolulu and Salt Lake City, and other metropolitan areas are beginning to implement it. When released on the Internet as Open Source software in 2000, over 300 planners, academics, and consultants on five continents downloaded UrbanSim. The requirements for new analytical tools, and the design of UrbanSim in response to these requirements, are described in the following sections.

The Planning Context: An Analysis of Requirements

The planning context for land use and transportation has evolved rapidly over the past decade, calling for the development of new analytical tools. In this section, requirements are grouped into representational, operational, and analytical aspects.

Figure 1. Local Markets for Real Estate, Labor and Infrastructure



Flow of consumption from supplier to consumer

Regulation or Pricing

Requirement 1: Represent Local Markets

Models must represent the interplay between local political institutions and local markets for land, housing, labor, and transportation. Growth management polices attempt to influence these markets, with active governmental intervention through the provision of infrastructure, regulation, and pricing policies. A policy objective of achieving densification around transit nodes, for example, not only requires regulatory change to zoning codes to allow greater density, but also requires that developers find profitable investments consistent with the public objectives, and that households and businesses find these locations attractive and affordable. Figure 1 portrays these linkages between actors, markets, and governmental intervention. Shaded boxes represent the markets, and non-shaded boxes represent actors that supply and demand the products and services exchanged in these markets. The market for infrastructure is for the services afforded by the infrastructure, such as the access to jobs provided by the transportation infrastructure.

Requirement 2: Represent Local Governments

Metropolitan areas in the U.S. are highly fragmented by local governmental units such as counties, cities, school districts, and special utility and transportation districts. Each of these has an institutional mission, authority and set of policies. The fragmentation of government is a policy concern in its own right (Downs, 1994), but also implies that land use and transportation policies need to be represented in models in ways that reflect local control of these policies. Comprehensive land use plans are under local control, and affordable housing or other growth management targets are generally left to local governments to implement. Much of the data that might be used in modeling land use such as parcel maps and assessor files are also maintained locally. It is therefore imperative that models represent the scope and roles of local governments, at least through a representation of jurisdictional variation in land use and transportation policies.

Requirement 3: Represent Environmental Constraints

Environmental conditions increasingly influence development choices. Concerns about preserving sensitive habitat areas such as wetlands or riparian buffers lead either to costly mitigation requirements or to outright constraints on development in affected areas. Risk of natural hazards motivates policies to limit development on floodplains, steep slopes, or near seismic features. Endangered Species Act actions such as the recent listing of several species of Chinook Salmon in streams in the urban areas of the Puget Sound have increased the degree to which environmental considerations are influencing land use and development policy. Clearly, new models need to be able to represent these environmental features, and the development policies that apply to them.

Requirement 4: Represent High Level of Geographic Detail

Accessibility measures that are generated using regional travel models are often referred to as measuring 'regional accessibility', and contrasted with neighborhood-scale, or 'local accessibility' (Handy, 1993). Incorporating local accessibility into new models, reflecting the potential impact of new urbanist design on pedestrian travel, requires a different approach than interfacing with a regional travel demand model. In practical terms, a major constraint on current travel models appears to be the reliance on a zonal system that is too coarse for pedestrian-scale analysis, since the models are geared toward the analysis of the transport networks dominated by vehicular traffic, and many zones are far larger than the scale relevant to the pedestrian. Given the active debate in the planning field about the potential of neo-traditional neighborhood design, or new urbanism, to promote changes in travel behavior that reduce vehicle miles of travel and increase transit and pedestrian travel, new models need to support urban-design scale analysis.

By the same token, a variety of other policies of interest, such as comprehensive land use plans and environmental constraints, require substantial geographic detail to represent realistically. Land use plans and zoning may be most readily interpreted at the parcel level, whereas environmental features follow topographic and other natural boundaries. The norm for representing and modeling environmental characteristics is a high-resolution grid, with cell sizes of 30 by 30 meters or larger. High-resolution data, and heavy use of Geographic Information Systems to manage these data, are required to address the range of policies that have been identified within the planning context.

Requirement 5: Facilitate Public Participation

Land use and transportation planning must accommodate increasing levels of public participation, as exemplified in the Portland LUTRAQ process (LUTRAQ, 1993). Community interest groups are increasingly informed and involved in the policymaking process, opening the technical planning process to unprecedented scrutiny. Requirements for new tools, then, include transparency, to support a planning process that is iterative and participatory. The role of the planner in this process is evolving from that of a technocrat developing forecasts in a closed environment to one of a facilitator, using information and analysis tools to help inform public debate about major choices.

Major decisions about transportation and land use choices involve a variety of stakeholder groups holding widely differing values and preferences. The role of land use and transportation models should be framed within this context as facilitating dialog and exploration of trade-offs and potential compromises among these stakeholders and their interests.

Requirement 6: Develop Flexible and Open Software

Most current transportation model systems are implemented in commercial transportation modeling software derived from the original federally developed UTPS software from the early 1970's. Much of what has been learned in software engineering over the past two decades about modular programming to promote flexible software that can be reused, maintained, and adapted to changing conditions, is lacking in current transportation and land use model implementations. Perhaps this is one reason that models have evolved fairly slowly over the past three decades.

A second constraint of much of the existing software is that it is proprietary and typically very expensive to license. This has several side effects. First, planning agencies must invest heavily in a proprietary software system, and are unable to directly inspect or modify the source code (the original program as seen by the programmers, not the compiled version as seen by users). This restricts the ability of planners using these tools to add new features or fix problems in the software. It also limits open scrutiny of the assumptions and methods used to implement the models. Finally, the complexity and closed 'black-box' nature of the current models tends to elevate and isolate the role of the technological planner that runs the models, in effect isolating them from the planning processes in which they are key participants, and ultimately making the models less relevant to the decision-making process.

Compared to this proprietary approach, there has been growing interest in the software industry in 'Open Source' software development that allows software source code to be freely accessed, modified and redistributed. This approach was made most visible by the Linux operating system, and has been embraced by an increasing number of private companies. Public investments in software development efforts, such as complex land use and transportation models, are increasingly likely to examine this licensing approach in order to reduce public expenditures and to increase the openness, flexibility, and robustness of the resulting software. This approach was taken as a requirement for new model development.

Requirement 7: Facilitate Visualization and Evaluation of Results

Planners and current model users also demand tools that facilitate visualizing and evaluating model results. Land use and transportation models produce massive amounts of data, far more than can be readily interpreted by reviewing tables of numbers. In addition, the need for significant public participation suggests that methods of translating the voluminous output of models into visual representations such as maps and charts that can be readily and intuitively understood by non-experts are required.

Means of comparing and summarizing the differences between scenarios in ways that various stakeholders can evaluate with respect to their interests are also required. Indicators that measure performance on policy objectives should be readily available, and users should be able to create new indicators for evaluation. Ultimately, the models need to be able to support analysis of trade-offs between the objectives of stakeholders, in order to facilitate informed public deliberation.

Requirement 8: Analyze Regional Effects of Transportation on Land Use

The first requirement for new models, as noted in the review of federal legislation, and as reinforced in growth management legislation in several states, is that models should be able to predict the effects of transportation investments and policies such as transportation pricing on land use. The term land use, as used in this paper, encompasses real estate development and household and business location.

Planning research has been divided about the degree to which accessibility influences these location choices, in an era of low-cost auto travel and ubiquitous freeways (Giuliano, 1993). Models need to be structured carefully in order to avoid imposing an assumption about the importance of accessibility. The degree to which access is important as compared to other factors such as housing price and neighborhood quality should emerge from empirical analysis, and not be imposed by the model structure.

New models must also better address the influence of multi-modal accessibility. Measures of transportation accessibility should include public transit and non-motorized modes of travel, and should reflect other aspects of travel such as fees, transfers, and wait times. Walk access to transit stops or stations is an additional important element in evaluating multi-modal accessibility and its potential effects on residential and business location choices.

An operational constraint is that most MPOs have made significant investments in their current transportation model systems, so that in the short-term, model development needs to focus on land use models that can be linked to existing transportation models. Over the longer-term, as MPOs transition to newer transportation modeling approaches such as activity-based models, flexibility is needed to integrate land use and transportation models more closely.

Requirement 9: Facilitate Complex Policy Evaluation Processes

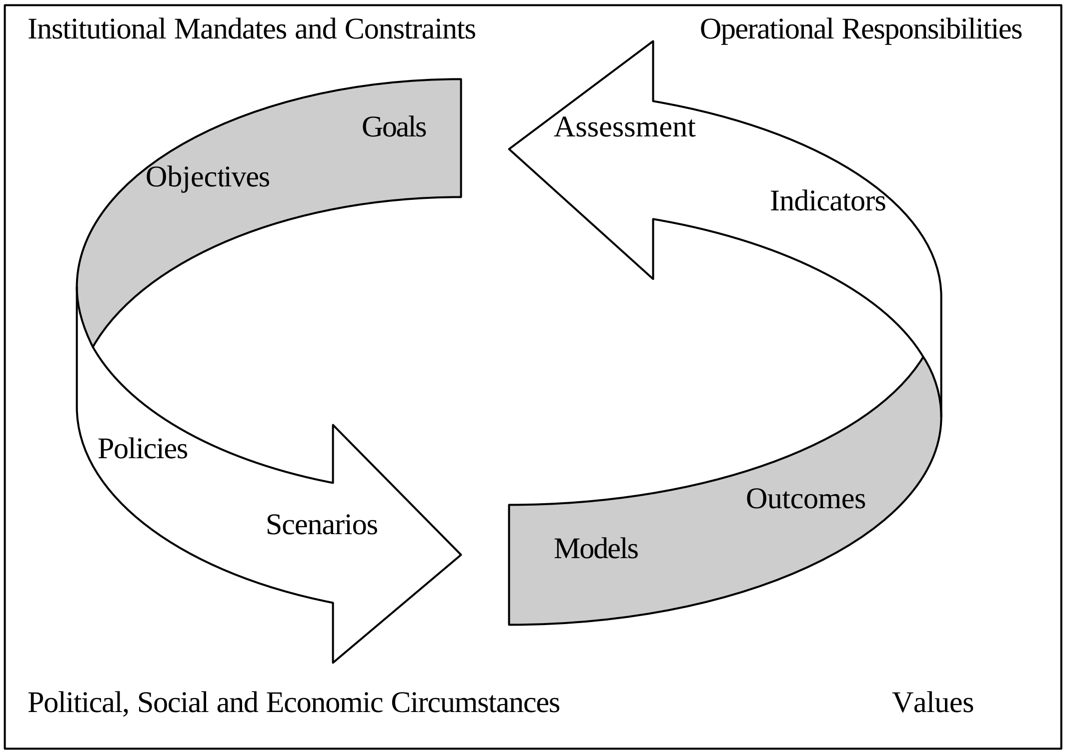
There is clearly more to the policy context for growth management than the estimation of induced land use effects of transport investments. Growth management strategies are complex, multi-faceted, and difficult to assess. New concerns are being balanced against congestion, including housing affordability, preservation of open space and agricultural land, protection of environmentally sensitive areas, spatial mismatch of low income population and new job growth, social equity, poverty concentration, and fiscal disparities between central cities and suburbs (Downs 1994; Orfield 1997). In addition, policy initiatives are being taken simultaneously on multiple fronts, and the interactions between these are likely to produce trade-offs and unintended consequences. Models therefore need to be able to address how various land use and transportation policies, and their combinations in packages, or policy scenarios, will affect land use, transportation and environmental outcomes.

Regulatory policies often take the form of restricting actions in some systematic way, such as zoning constraints on the physical development of land that restrict developers to certain land uses and densities. Pricing policies such as taxes, development impact fees, and congestion pricing affect economic decisions made by businesses and households through their individual choices in the markets for land and travel. Infrastructure investments impact accessibility, travel costs, and development costs, and thereby influence physical development and location choices indirectly but significantly.

Figure 2 shows a proposed view of the use of models to support the planning process for land use and transportation. It depicts a cycle of goal formation, identification of objectives, specification of policy instruments, combination of policies into scenarios, use of models to test these scenarios by producing outputs, development of indicators of performance against policy objectives, and ultimately assessment of further refinement of policy strategies, including potential revision of goals and objectives.

Figure 2.

The Role of Models in a Local Policy Process



Requirement 10: Analyze Urban Development as Dynamic Process

The practice of growth management, unlike the traditional practice of long-term planning for infrastructure, is focused on managing changes at the margin. It suggests a process of monitoring, evaluation, and adjustment of growth management policies adaptive and attentive to short-term effects of policies. The need to use models to support shorter-term strategic planning and assessment of impacts of growth management policies requires a significant departure from the requirements for long-term infrastructure planning, which has traditionally relied on economic equilibrium analysis.

Equilibrium analyses typically ignore the adjustments required to move from the initial conditions to the hypothetical equilibrium conditions and assume economically rational behavior from all individuals and firms. This clearly oversimplifies the situation, and may lead to especially erroneous analyses when we look at short time frames in which the world clearly departs from these assumptions. Consider, for example, the time required for real estate developers to respond to market signals and take development projects through the lengthy process of land acquisition, financing, planning, subdivision, permit review, site preparation, construction, and marketing to consumers. By the time their investment decisions become real estate products available on the market, the initial conditions that prompted the investments may have changed radically, reflecting the familiar pattern of cyclical over-building. Real estate development, by its nature, is generally out of equilibrium.

Equilibrium approaches may also produce biased predictions of the effects of a given policy by overestimating the degree to which real estate development and household and business relocation respond to changes. The transaction costs of moving and the psychological inertia of long-term residence, especially for the elderly, are likely to dampen the rate of residential mobility compared to that predicted from an equilibrium assumption.

Assessment of Requirements

These analytical requirements are very similar to the set of recommendations for new model development that were formulated by an international conference on land use modeling convened by the Travel Model Improvement Program in Dallas in 1995, and summarized in Table 1 (Weatherby, 1995). They are also quite consistent with a proposed design for an 'ideal' land use model (Miller, Kriger and Hunt, 1998). The design and implementation of UrbanSim, described in the following section, achieves most of these requirements, and much of what Miller, *et. al.* call for in their ideal model design.

TABLE 1.

1995 TMIP Recommendations for New Model Development

Review of Existing Models

- There has been insufficient validation and testing of models in the U.S.
- Most existing models are not sufficiently sensitive to policy issues, nor are they geared to understanding by non-modelers.
- Existing models do not adequately incorporate the land development decision-making process, nor are they sufficiently linked to consumer choices.
- Current land use models are not adequately linked to transportation models or environmental models and do not allow a valid assessment of the interaction among land use, transportation and environmental impacts.
- There are many incompatibilities of zonal systems being used.
- Data, especially employment data, is a tremendous problem for existing models.
- There is an absence of a clear, describable basis of theory for current land use models.
- Generally, land use models are far too dependent on transportation modeling output and assumptions, and there is insufficient interaction between the two.
- Public transit is not adequately represented in land use or transportation models.
- In general, there is too little behavioral content to the existing land use models.
- Existing models require excessive resources, effort and execution time.
- Existing models are not capable of accounting for urban development as an incremental process, but are static cross-sectionally.
- Current models appear suitable for predicting urban sprawl, but are unable to assess controlled growth.

- Modeling efforts should move fairly quickly toward random utility-based models.
- New models must be behaviorally based, and the underlying theory should be clear. Major research is required into the behavior of the actors involved.
- New models should place greater emphasis on their use for policy analysis, planning, and sensitivity testing, within an integrated land-use, transportation and environmental framework.
- Models should be more sophisticated about varying temporal and geographic scales relevant to different processes in urban development.
- Models must be capable of bi-directional aggregation/disaggregation.
- In developing new models, the cost-effectiveness of the modeling strategy as a whole should be studied.
- Microsimulation holds promise, and should be considered in any new modeling system, although it is very data hungry. It should also not be the only method considered. Research into synthetic household data at the micro-level and use of other existing databases will be required.
- Model development should draw on disciplines beyond transportation, including economics, geography, logistics, computer science, statistics, and planning.
- New models should be modular in nature, not monolithic.
- GIS must be used with any new models developed. Remote sensing should be investigated as a means of monitoring land-use.

- With travel costs becoming less important determinants of location choices, and amenities and other factors becoming more significant, new models should not be structured to use travel costs as the principal influence on location.
- The minimum time frame for new model development may be five years.

Source: Adapted from Weatherby (1995)

The Design of UrbanSim

A design for new analytical tools to address the preceding requirements has been developed, implemented in software, and applied in three metropolitan areas. These new tools are collectively described as the UrbanSim model system. This section reviews the design of the UrbanSim database, model system, integration with transportation, and scenarios for policy analysis.

Database Design

The design of UrbanSim responds to the preceding requirements by organizing the model database to represent the principal actors related to urban development and markets. The actors represented in the model system are households, jobs, and developers. Households are maintained in a database that represents each household in the metropolitan area, and their primary characteristics relevant to modeling location and travel: household income, size, age of head, presence of children, and number of workers. Other household attributes could be readily added to this. Employment is represented in the database as individual jobs and their employment sector. Employment can also be represented at the level of business establishments, with the sector and employment size of the establishment.

Developers are not currently represented in the database in the same way as households or businesses, with individual records representing each development company. Instead, the database represents the land use and real estate development at each location in the region. Developers are implicitly, rather than explicitly represented. One might think of this as a virtual set of developers that may be able to influence real estate development or redevelopment at each location, as described in the next section.

The geographic unit of analysis in the current model is a grid cell. That is, locations are defined by cells of 150 by 150 meters. The location grid allows other key features to be explicitly represented in the database design. Governments are represented in the database by assigning county and city codes to each location. Environmental features are also defined explicitly, by defining the environmental characteristics at each location. Policies may then be defined in ways that are specific to an individual county, city, environmental characteristic, or even an individual grid cell.

The process of developing the database to run the model involves processing land use parcel data in GIS form, employment records from unemployment insurance records, household travel surveys, census data, and environmental features such as wetlands. A more detailed description of the parcel data preparation process has been reported elsewhere (Waddell, Moore and Edwards, 1998). Household records are generated from census data in a simplified version of the approach used in the TRANSIMS model (Beckman, et al, 1995).

Figure 3 shows one 150 meter grid cell in a central Seattle neighborhood of Queen Anne, over a digital orthophoto and parcel boundaries. Parcel data are collapsed into the cells to generate composite representations of the mix and density of real estate at each location, labeled development types. These development types are somewhat analogous to the development typology developed by Calthorpe (1983), in that they represent at a local neighborhood scale the land use mix and density of development. Table 2 provides the rules for classifying grid cell development into types, based on the combination of housing units, nonresidential square footage, and the principal land use of the development. The grid cell shown in Figure 3 would be classified as a development type of R8, or high-density residential, on the basis of containing 98 housing units and no non-residential square footage.

TABLE 2.

Development Type Classification

DevType	Name	UnitsLow	UnitsHigh	SqftLow	SqftHigh	Primary_Use
1	R1	1	1	0	999	Residential
2	R2	2	4	0	999	Residential
3	R3	5	9	0	999	Residential
4	R4	10	14	0	2,499	Residential
5	R5	15	21	0	2,499	Residential
6	R6	22	30	0	2,499	Residential
7	R7	31	75	0	4,999	Residential
8	R8	76	65,000	0	4,999	Residential
9	M1	0	9	1,000	4,999	Mixed_R/C
10	M2	10	30	2,500	4,999	Mixed_R/C
11	M3	10	30	5,000	24,999	Mixed_R/C
12	M4	10	30	25,000	49,999	Mixed_R/C
13	M5	10	30	50,000	9,999,999	Mixed_R/C
14	M6	31	65,000	5,000	24,999	Mixed_R/C
15	M7	31	65,000	25,000	49,999	Mixed_R/C
16	M8	31	65,000	50,000	9,999,999	Mixed_R/C
17	C1	0	9	5,000	24,999	Commercial
18	C2	0	9	25,000	49,999	Commercial
19	C3	0	9	50,000	9,999,999	Commercial
20	I1	0	9	5,000	24,999	Industrial
21	I2	0	9	25,000	49,999	Industrial
22	I3	0	9	50,000	9,999,999	Industrial
23	GV	0	99,999	0	9,999,999	Government
24	VacantDevelopable	0	0	0	0	VacantDevelopable
25	Undevelopable	0	0	0	0	Undevelopable

Parcel and employment data are inherently large and messy files, and may be incomplete or unavailable in some places. Much of the work on the applications of the model described here has gone into developing tools to facilitate the integration and reconciliation of these data sources, but much more remains to be done before this can be described as a ‘user-friendly’ process. Ultimately, however, even aggregate models and data rely on disaggregate data sources such as these, and we are better served by working with data in its original form where possible, since it is easier to interpret and validate. In addition, much parcel data is being converted to GIS and improved at a rapid pace, and such data are becoming less of a problem to access every year.

FIGURE 3.
150 Meter Grid Cells as Unit of Analysis for Location and Development

Model Design

The design of UrbanSim differs significantly from several existing operational modeling approaches, including the spatial-interaction DRAM/EMPAL models developed by Putman (1983); the spatial input-output TRANUS and MEPLAN models, developed respectively by de la Barra (1989) and Echenique et al. (1990); the GIS-based California Urban Futures Model developed by Landis (1994; 1995), and the CATLAS (and later METROSIM) model developed by Anas (1982). These models are discussed in detail in various reviews, (Anas, 1987; Harris, 1985; Kain, 1985; Paulley and

Webster, 1991; Southworth, 1995; Wegener, 1994, 1995; Miller, Kriger and Hunt, 1998; Parsons Brinckerhoff, 1998). The pitfalls of large-scale urban models were convincingly articulated almost three decades ago (Lee, 1973; 1994), and remain significant concerns. The design of UrbanSim has been well informed by these criticisms of prior modeling efforts, as well as by advances in theory, computation, and econometric methods.

The structure of UrbanSim includes components reflecting the behavior of households, businesses, developers, and governments, all interfaced through the real estate market. By focusing on the principal agents in urban markets and the choices they make about location and development, the model deals directly with behavior that planners, policy makers, and the public can readily understand and analyze. This behavioral approach provides a transparent theoretical structure different from 'black-box' or abstract urban models that do not clearly identify the agents and actions being modeled. The transparent structure allows users to incorporate policies explicitly and to evaluate their effects.

Inputs to the model include base year land use, population and employment, regional economic forecasts, transportation system plans, land use plans, and land development policies such as density constraints and environmental constraints. The model predicts the location of employment and households; the location, type, and quantity of new construction and redevelopment by developers; and the prices of land and buildings. Two model components, demographic and economic transition, predict changes in the distribution of households and employment by type (e.g., age, income, and employment by industry) at the regional level.

The core model components in UrbanSim correspond to the key actors and choices in urban markets for real estate, labor, and infrastructure: household mobility and location, employment mobility and location, and real estate development. In the household mobility and location models, the system 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 location. These choices are modeled using logit analysis, a technique that has been widely used for problems of predicting individual choices, such as travel mode choice (McFadden, 1973, Ben Akiva and Lerman, 1987). The specification of each model component draws on substantive theory and empirical research in urban planning, economics, geography, and sociology.

In the employment mobility and location models, businesses make choices regarding mobility, real estate type, and location of jobs. Household and business characteristics influence choices, as do location attributes such as accessibility and prices. In the real estate development component, the model simulates developer choices to develop real estate on vacant or developed sites, or to convert real estate from one use to another, subject to constraints imposed by governmental policies such as zoning and infrastructure availability. A real estate price model component predicts changes in real estate prices based on the changing conditions in the urban landscape.

The model system runs on events generated by the model components. Each of the choices made by households, businesses, and developers are evaluated annually; actions are scheduled as events to be implemented in the current or a future year. Large development projects may be scheduled with multi-year timetables. In addition to model-generated events, the model system has been designed to accommodate information that planners have about pending development, corporate relocations, or policy changes. These may be specified in input files as user-specified events and scheduled for implementation just like model-generated events.

Transportation Interface Design

UrbanSim currently interfaces with existing travel forecasting models used by MPOs to account for the effects of changes in the transportation system on land use. Travel accessibility for households to employment and shopping, and for businesses to labor market and other business activity, are measured in the form of accessibility indices. These accessibility indices combine the distribution of opportunities (e.g. shopping) at each zonal destination and the ease of reaching these destinations. The model does not assume that all households respond to accessibility in the same way, or that it is an overriding criterion for making location choices. Retired persons, for instance, would be less influenced by accessibility to job opportunities than working age households.

Most travel demand models in use in major metropolitan areas today are derived from the traditional four-step travel model system that uses trip generation, trip distribution, mode choice, and traffic assignment. The mode choice model in many of these models is based on a formulation that allows the creation of a composite measure of the ease of travel between two zones. This composite measure has the advantage of incorporating multiple modes of travel, and multiple attributes such as cost, time, and convenience into a single measure of the 'disutility' of travel between two zones. Alternative and more robust measures can be derived from the emerging generation of activity-based travel models, and these measures can be used in UrbanSim as well.

Since there are two elements to the accessibility measures used in UrbanSim, the distribution of activities and the ease of travel between zones, and since these two components are predicted by separate land use and transportation models, the practical question arises of how frequently to link the models. Major transportation improvements such as the opening of a new section of a freeway are likely to be infrequent, suggesting a linkage of the models triggered by major transportation system changes. However, the evolving pattern of land use and its spatial distribution of activities will influence the patterns of travel and congestion even when there have been no changes in the transportation network. So the question of how frequently to interface the land use and travel models is both a function of changes in the transportation network and the rate of change in land use patterns. To allow flexibility, UrbanSim can be interfaced with travel models as needed, even annually. In practice, annual interaction of the models is likely to be both unnecessary and impractical, since travel model systems generally require excessive processing and manual intervention.

UrbanSim also incorporates local access measures, corresponding to the activities that can be reached by non-motorized travel over a short distance of approximately 1/3 mile, using spatial queries of the land use database maintained by the model. Achieving this scale of analysis makes UrbanSim the first operational urban model system to support analysis of location and travel behavior at a level that effectively represents pedestrian and bicycle modes of travel. Given the ongoing debate over the potential influence of neo-traditional urban design on travel behavior, this innovation should provide a basis for making more systematic assessments of the effects of urban design-scale policies on both location and travel behavior. Traditional zone-based travel models are severely limited by poor performance on intra-zonal travel and insufficient representation of non-motorized travel modes. By creating a more detailed basis for the land use model, the main barrier to the improvement of transportation planning to address non-motorized modes and the integration of urban design policies, has been effectively removed.

Scenario Design for Policy Analysis

UrbanSim allows users to specify policy inputs and assumptions, generate and compare scenarios, compute evaluation measures, and query the database of results. The user interface is focused on the interaction of the user with the inputs to each scenario. Scenarios are defined by the user to consist of a particular combination of development policies represented by appropriate input data such as comprehensive plans, infrastructure plans, urban growth boundaries, and development restrictions on environmentally sensitive lands. These policies are linked to locations at a grid cell, zonal, municipal, county, or metropolitan scale.

Broadly speaking, government agencies influence the land development process through a combination of land use regulations and infrastructure provision. These are frequently combined into packages that attempt to foster a development pattern in ways that promote planning objectives, for example by pursuing one of the following community visions:

- Containing development within an Urban Growth Boundary
- Focusing development along primary transportation corridors
- Focusing development within centers connected by multi-modal transportation
- Diverting development into new or existing satellite communities
- Encouraging development in parts of the region with underutilized infrastructure
- Promoting development of impoverished areas.

The translation of these scenarios into inputs to UrbanSim involves interpreting policies and creating input files for the model that represent these policy interpretations.

Interpreting the comprehensive land use plan is a key part of constructing a policy scenario in UrbanSim. Each land use plan designation may be described as a set of restrictions on development options. For example, the plan designation of 'agricultural' may not be allowed to convert to any developed urban category under restrictive interpretation of the land use plan, or to only rural density single-family residential under a less restrictive interpretation. The comprehensive plan guidelines for a local region should spell out the intended interpretation of these plan designations, but the user of the model may wish to assess the impact of altering these constraints as a matter of policy testing.

These interpretations of the land use plan are entered in an input file for the model that contains a concise set of development restriction rules to apply in a scenario. These development regulations may be coded for an entire metropolitan area, for individual counties, cities, or special overlays such as environmentally sensitive lands or urban growth boundaries. The regulations are applied hierarchically by region, county, city, and overlay. That is, city regulations override county regulations, and county regulations override regional policies. These regulations then restrict the outcomes that the model will consider for the affected areas to be consistent with the policy scenario.

Increasingly, environmental factors are being considered in the development of land use plans. Local zoning codes usually identify areas where such factors are an issue, and adopt additional development constraints. UrbanSim accounts for environmental development constraints by identifying the grid cells that may be affected and allowing the user to tailor the development regulations that apply to these areas. Examples of environmental factors used in current applications of the model include:

- Areas with steep slopes
- Areas delimited as part of a stream buffer
- Wetlands
- Floodplains
- Areas considered to be in 100 year floodplain areas

The model accounts for areas with the above conditions by allowing the user to modify the allowable development regulations in the protected area. The user may treat an Urban Growth Boundary (UGB) as a policy constraint, analogous to an environmental constraint, by tailoring the development regulations that apply to the land area outside the UGB. Other policy-targeted areas can be incorporated into the model as overlays and treated in a similar way, such as enterprise zones or other special planning districts. Using this combination of policy inputs, the UrbanSim design affords a tremendous degree of flexibility in representing real land use policies, and at a high degree of geographic detail. The interaction of different policies by city, county and special environmental or planning overlays provides a rich environment in which to perform complex policy analysis in support of land use, transportation and growth management.

Conclusions

The UrbanSim project has made significant progress on the agenda of developing analytical tools to support challenging issues related to metropolitan planning of land use, transportation, and growth management. The requirements developed in the paper have been broadly met by the design and implementation of the current version of UrbanSim. A summary of the requirements and the ways in which the current design meets each requirement is shown in Table 3.

Empirical results from application of the model (Waddell, 2000a), more detailed specifications of the model (Waddell, 2000b), its theoretical foundations (Waddell and Moore, forthcoming), and the underlying software infrastructure (Noth, Borning and Waddell, 2000), have been reported elsewhere. The UrbanSim software is distributed as Open Source software under the GNU General Public License, which allows anyone to use, modify and redistribute the source code at no cost. It is available at www.urbansim.org.

Extension of the model system to incorporate environmental processes such as land cover change, nutrient emissions, and water demand are now underway (Waddell and Alberti, 2000). Additional effort is being focused on developing a graphical user interface, robust data integration tools to support the development of local databases for use in model applications, calibration tools to support the estimation of local coefficients for the model equations, tools for visualization and construction of evaluation indicators, a web-interface for distributed access to the system over the Internet, and development of a modeling language to facilitate rapid construction and testing of new model components or modification of existing components.

Table 3.

Responsiveness to Design Requirements

Requirement	Response
Represent local markets	Local markets for real estate are explicitly represented, including land, housing, and nonresidential real estate. The model simulates land development and redevelopment, occupancy of housing and nonresidential real estate by households and jobs, and real estate vacancies and prices.
Represent local governments	Counties and cities are explicitly represented in the database, and may have individual policies. Special planning areas such as Urban Growth Boundaries or enterprise zones can also be geographically represented and have special policy application.
Represent environmental constraints	Environmental features such as wetlands, floodplains, stream buffers, high slope areas, and others is explicitly represented for each location.
Represent high level of geographic detail	The current applications of the model use a 150 meter grid cell as the unit of analysis, though cell size is determined by the user. Spatial analysis of neighborhood characteristics allow representation of urban design scale.
Facilitate public participation	The behavioral approach to the model design is intended to make the functioning of the model more transparent and credible to the public. The extensive orientation of the model to testing user-defined policy scenarios is intended to facilitate public involvement and interaction. This remains an area for further development.
Develop flexible and open software	A new software architecture has been implemented to facilitate modular model development and evolution. It is open source software, freely available from the project website (www.urbansim.org).
Facilitate visualization and evaluation of results	A prototype visualization system has been developed but not released. Arcview is being used to support visualizations currently. Future effort is planned for an extensive facility to develop indicators and evaluation measures.
Analyze effects of transportation on land use	Multi-modal transportation effects can be examined on household location, employment location, real estate development, and real estate prices. Both regional and local accessibility are examined.
Facilitate complex policy evaluation processes	The model system is organized around the use of policy scenarios, which can be combined and systematically compared. Further work on user interface, indicator development, and other tools to facilitate analysis of trade-offs between policy scenarios is planned.
Analyze urban development as dynamic process	The model system is the first to make operational a dynamic model design, using annual time increments. The time steps can be modified.

Metropolitan transportation and land use planning must be more effectively integrated than has been traditionally the case. This integration requires robust analytical methods, and should be open to public scrutiny and deliberation in ways that have not been accomplished in the past. Simulation models can and should be part of this deliberative policy process, but they will have to come out of the 'black box' and become instruments that facilitate discussion between local governments and their constituents. The challenge of balancing multiple objectives and agendas within urban areas in the U.S. and abroad have grown increasingly intractable politically, and this work represents a small effort to contribute to more deliberative and informed metropolitan governance. It is, in closing, only one step forward. What lies ahead is a challenging agenda to refine the analytical tools for metropolitan and local planning, make them more accessible and robust, and to generate collaboration in the development and use of planning methods such as these to help communities that want to grow smarter.

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