Simulating the Effects of Metropolitan Growth Management Strategies

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Introduction

The success of growth management in Portland, Oregon has begun to reach mythical stature, so widely has it been acclaimed (DeGrove with Miness 1992; Abbott *et al* 1994; Hales 1991; Knaap and Nelson 1992; Leonard 1983), although doubts about the replicability of this success have also been voiced (Lewis, 1996). Portland, Oregon may well be unique in many respects, but many other states and metropolitan areas have begun adopting variations of these growth management strategies, and some have long histories of growth management.

Within the Oregon growth management context, the Oregon Department of Transportation launched in 1996 an ambitious effort to develop enhanced analytical tools to evaluate the interactions between transportation and land use. This project, dubbed the Transportation and Land Use Model Integration Project (TLUMIP), 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 the TLUMIP effort was the development of UrbanSim, a new metropolitan-scale land use model for use by Metropolitan Planning Organizations (MPOs) in Oregon. This paper focuses on the development of UrbanSim and its application to the evaluation of metropolitan growth management strategies in Oregon[1].

The UrbanSim model development process is perhaps unique in that it was designed specifically to address the policy analysis requirements of metropolitan growth management, with particular emphasis on land use and transportation interactions. The organization of the paper begins with a description of the policy context that motivated the model, followed by an overview of the model design, its relation to other research, and preliminary results from its application to a case study in Eugene-Springfield. Finally, we develop an agenda for further research.

The Policy Context

The relationships between land use, transportation, and the environment are at the heart of growth management. There is a rich theoretical and empirical literature that examines the nature and extent of these relationships (Downs 1992). The recognition that construction of new suburban highways induces additional travel, vehicle emissions, and land development has reshaped the national policy context for metropolitan planning. The passage of the Clean Air Act Amendments of 1990 and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) have placed growth management front and center on the agendas of metropolitan planning organizations. Subsequent legal challenges to the metropolitan transportation planning process in the San Francisco Bay Area (Garrett

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[1] We wish to acknowledge the financial support for the development of the UrbanSim model from the following organizations: Oregon Department of Transportation, National Cooperative Highway Research Program, Oahu Metropolitan Planning Organization, and Governor's Office of the State of Utah.

and Wachs 1996) and more recently in Chicago have added a sense of urgency to these federal mandates. Previously, most MPOs had focused on the need to finance and build new transport capacity to relieve congestion. Land use effects of transportation investments had, as a result, largely been ignored.

The planning methods used by MPOs to inform regional transportation plans are typically based on a variation of the traditional four-step travel model system developed decades ago for the narrow purpose of solving the engineering problems of sizing capacity to reduce congestion. Land use assumptions about the future were developed through political negotiations, Delphi methods, or by other more or less formal means. In some cases, land use models were developed, but rarely were the land use effects of transportation investment considered. The only land use model in use by more than a handful of MPOs in the U.S. today, and which predicts land use effects of transport improvements, is the DRAM/EMPAL model system (Putman, 1983).

But there is more to the policy context for growth management than the estimation of induced land use effects of transport investments. The growth management strategies being implemented in Oregon and other states 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 (see for example Downs 1994; Orfield 1997). In addition, policy initiatives are being taken simultaneously on multiple fronts, and the interactions between these are likely to produce tradeoffs and unintended consequences.

Most of these new considerations are mediated in some form by markets for land, housing, labor, and transportation. Public action may influence these markets by regulating them, influencing the costs of supply or consumption, or creating infrastructure that transforms the available options, such as for development or location. Some of the new growth management concerns are geographically quite specific, such as the effect of new urbanist design on travel behavior, while others are spatially diffuse, such as the effect of an Urban Growth Boundary on density and housing affordability.

Simply put, the analytical tools available today are not up to the task of assisting policymakers and planners in sorting through these issues, devising growth management strategies, and evaluating their impacts. The Oregon Department of Transportation launched the Transportation and Land Use Model Integration Project with these considerations in mind. The decision was taken in 1996 that existing tools were not adequate to address the needs of metropolitan planning and growth management, and the development of a new generation model was begun. We turn now briefly to the Oregon policy context that provided the fundamental requirements for the development of the new model system.

Three policy initiatives in the State of Oregon combine to form what is perhaps the most proactive state program in the United States to effectively manage urban growth and its consequences. The Oregon Transportation Plan (OTP) explicitly links transportation and land use and provides a multi-modal context for statewide transportation plans and project development. The Transportation Planning Rule (TPR) specifies the relationships between transportation and land use. It defines the characteristics of acceptable transportation plans, establishes standards for transportation system performance, and requires explicit linkages between local land use and transportation planning processes. The Oregon State Benchmarks (OSB) establish measurable performance standards for a wide range of state and local governmental activities including transportation and land use. These three documents describe the following policy objectives that are particularly germane to the development and use of the urban simulation model[2].

- Consistency between transportation and land use planning
- Consistency with comprehensive plans and urban growth boundaries
- Minimize development pressures on the urban fringe
- Support Compact, mixed use development including infill and redevelopment
- Evaluate land use alternatives for meeting transportation needs
- Limit parking supply in metropolitan areas
- Access management
- Statewide economic development
- Transportation system efficiency
- Multi-modal accessibility
- Demand and congestion management
- Reduction in automobile reliance and state vehicle miles traveled (VMT) per capita
- Reduce environmental impacts of urban development

These policy objectives are often further specified with specific quantitative targets and timetables. What the policy initiatives generally do not prescribe are the particular instruments to be used to achieve these objectives. Nor is it entirely clear that the specific targets set out in some of the policies are in fact fully achievable, since they are attempting to influence individual behavior. Some of the objectives may conflict with others, such as the desire to support compact, mixed use development, and statewide economic development objectives to better link rural producers to urban markets. Nevertheless, the cumulative effect of the myriad policy initiatives may well be the most comprehensive effort to manage metropolitan growth attempted to date in the United States. The specification of goals without a further prescription of the instruments to be used leaves considerable flexibility in implementation. It also suggests that the development of new analytical tools should support the development and testing of scenarios of combinations of instruments that include land and transportation regulation, pricing, and infrastructure.

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[2] For a more complete description of the specific policy initiatives that these objectives are drawn from, refer to the Appendix

This policy and planning milieu called for the development of a set of analytical tools that would provide a foundation for objective analysis of the effectiveness of combinations of land use and transportation instruments in achieving desired policy objectives. Such analysis is embedded within a broader political context in which the trade-offs between policy objectives must be evaluated. Land use and transportation planning are no longer the exclusive domain of planners or politicians, but must accommodate increasing levels of public participation, as the Portland LUTRAQ process has shown (LUTRAQ, 1993). Community interest groups are increasingly informed and involved in the policymaking process, and are opening the technical planning process to unprecedented scrutiny. This adds to the requirements for new tools the need for transparency. Tools need to be explainable to a non-technical audience. The days in which one might expect policymakers and the public to naively trust numbers simply because they come from a computer, if they ever existed, certainly do no longer.

The capacity to use models for shorter-term strategic planning and assessment of impacts of growth management policies required another departure from the requirements for long-term infrastructure planning, which often rely on cross-sectional and equilibrium assumptions in order to simplify the analysis. Srategic planning and evaluation of growth management shifts the focus towards the analysis of changes at the margin, with a recognition that current conditions heavily influence the ability of policies to change the urban landscape. Infrastructure and the built environment have very high durability, and actions such as growth management policies designed to increase compactness and density of residential development will not reshape cities in a day. Rather, changes will occur at the margins, and therefore may take long periods to affect the urban form of a metropolitan area.

Cross-sectional equilibrium approaches may also bias the anticipated effects of a given policy by overestimating the degree to which household or business relocation occurs as a response. Equilibrium approaches generally assume that all agents are freely and instantaneously mobile, have full information, and will relocate whenever conditions change to make their current location suboptimal. 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. Empirical analysis of mobility rates by type strongly supports this argument, with five-year mobility rates varying from near zero for households headed by someone over age 65 to nearly 100 percent for households headed by someone under age 29 (Waddell, 1998a). As a result of these considerations, a dynamic disequilibrium approach was preferred for the model implementation.

Finally, given the need to adapt tools to varying conditions in different metropolitan areas, the development of new tools required flexibility, and an ability to link to existing transportation planning models already in use by MPOs. The reliance on existing travel models is perhaps one of the only serious limitations imposed on the design of the new models in Oregon, since it subverted the opportunity to completely integrate land use and transportation models, at least in the short-run. That said, the development of closely linked land use and transportation models represented a substantial step forward in the state of planning and policy practice related to growth management, and was achievable within a short time frame. Longer-term integration of UrbanSim with next generation activity-based travel models is now underway in Honolulu (Waddell, 1998b).

With this overview of the policy context, we summarize the requirements for development of new analytical tools that guided the design of UrbanSim:

- Land use and transportation interactions
- Linkage to existing MPO travel demand forecasting models
- Markets for land, housing, and nonresidential space
- Develop and test scenarios: regulation, pricing, and infrastructure
- Environmental constraints
- High degree of spatial disaggregation
- Behavioral framework
- Dynamic disequilibrium

Behavioral Framework

As already noted, a clear behavioral framework was considered essential in order to be able to explain and develop consensus around the analytical basis for the new models. The behavioral framework providing the foundation for the model development is one that identifies the key actors that participate in the processes relevant to urban development and transportation. The key actors identified for the purpose of model development are households, businesses, developers, and governments.

Actors and Choices

The model is based on a view of urban development as it evolves over time and space as the composite outcome of the interactions of individual choices and actions taken by households, businesses, developers, and governments. The structure of the model includes components reflecting the behavior of these actors, interfaced through urban land markets. This behavioral approach provides a transparent theoretical structure that is much less like ‘black-box’ or abstract urban models that do not clearly identify agents and actions being modeled. As such, it becomes much more straightforward to explicitly incorporate policies and evaluate their effects.

Table 1 presents some of the key decision-makers and their actions that pertain to urban development in general and to land use and transportation in particular. The choices made by households, workers, businesses, and developers are modeled, and the choices by the public sector are treated as exogenous, and input to the model in the form of policy scenarios. The initial model design does not attempt to address the financial sector and its role in real estate development, nor does it currently represent individuals and jobs. Households and businesses are identified by type, with a potentially high degree of disaggregation. These and other omissions identified in Table 1 (or not listed there), are considered relevant but not as high a priority in the initial model development. The key actors and choices that are modeled are described briefly below.

Table 1
Decision-makers and Choices Affecting Urban Development

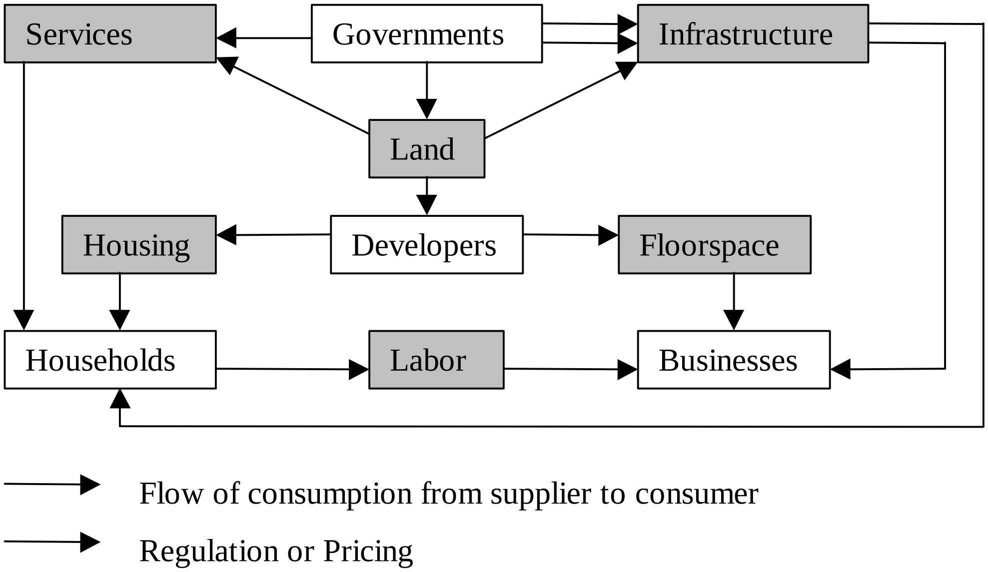
Decision-makers	**Actions**	
Market Choices (Endogenous)		
Household	*Mobility (move or stay)*	Housing Tenure (rent/own)
	Location (where to move)	*Housing Price (bids)*
	Housing Type (single/multi)	Auto Ownership
Worker	Labor Force Participation	Workplace Choice
	Job Change	Wage to Accept
	Full-time/Part-time	Mode of Transport to Work
	Multiple Jobs	Trip Linking
Business	*Number of Employees*	*Lease/Purchase Cost (bids)*
	Wages to Offer	*Mobility (move or stay)*
	Type of Space (office, retail, etc.)	*Location (where to move)*
	Tenure (rent/own)	
Developer	Land Purchase	*Redevelopment*
	Infrastructure Investment	*Land Use*
	New Development	*Density*
Public Policy Choices (Exogenous)		
Municipality	Tax Rate	*Development Fees*
	Tax Abatement/Incentives	Amenities (Parks)
	Zoning	Services (Fire, Police)
	Land Use Plan	*Infrastructure* (Transportation, Water, Sewer)
	Urban Design	
Transit Agency	*Transit Infrastructure*	*Levels of Service*
		Transit Fares
Lender	Loans for Mortgages	Development Loans
		Interest Rates
School District	Tax Rates	School Quality
Other Local, State, Federal Agencies	*Fees, Regulations governing land use, transportation, environment*	*Highway*, Rail, Ports, Airports

Note: Choices in *italics* are currently addressed in UrbanSim

Linked Markets

The behavioral approach is based on the representation of linked markets for land, housing, nonresidential space, labor, and infrastructure (transportation, water, sewer, etc). These markets are described by the interaction of demand and supply, with active governmental intervention in the markets through the provision of infrastructure, regulation, and pricing policies. Figure 1 portrays these linkages. Shaded boxes represent the markets, and non-shaded boxes represent actors that supply and demand the products and services exchanged in these markets. Note that the market for infrastructure is for the services afforded by the infrastructure, such as the access to jobs provided by the transport infrastructure.

Figure 1
Linked Urban Markets



Note that for every flow of consumption there is an offsetting flow of payments. Within the markets for land, housing and nonresidential floorspace these flows constitute rents. Payments for labor are in the form of wages, and payments to government for infrastructure and services are in the form of taxes and use fees. Property taxes flow from land (owners) to governments, as well. The market for government services such as education and public safety, with compensating property taxes, represent Tiebout shopping among jurisdictions by households, and are not currently incorporated into the model design. Neither is the labor market, with compensating wages.

In order to represent the operation of these markets, the model design must be explicit in its representation of the supply and demand quantities for each market, as well as the behavior that influences consumers and suppliers in each market, and how demand and supply interact over time to clear markets and adjust prices. The approach taken in designing UrbanSim was to develop an explicit inventory of businesses, households, land parcels, and buildings, and to simulate the production of new housing and commercial buildings, and the consumption of these by households and businesses.

Model Design

UrbanSim was designed to address the policy analysis requirements through the behavioral framework described in the preceding sections. We have now implemented this design in software, and calibrated it as a case study with data for the Eugene-Springfield metropolitan area.

Object-Oriented Design

This section reviews the model design and software implementation. The model has been developed in an object-oriented framework drawn from the computer science approach to object-oriented programming (Booch, 1994), which lends itself to the behavioral framework of this model. There is a straightforward translation between the urban actors and the physical features such as land, buildings, and infrastructure described above, and the 'objects' represented in the software. The attributes of these actors are implemented in the software as 'object properties'. Models that simulate behaviors are implemented as 'methods' associated with these objects.

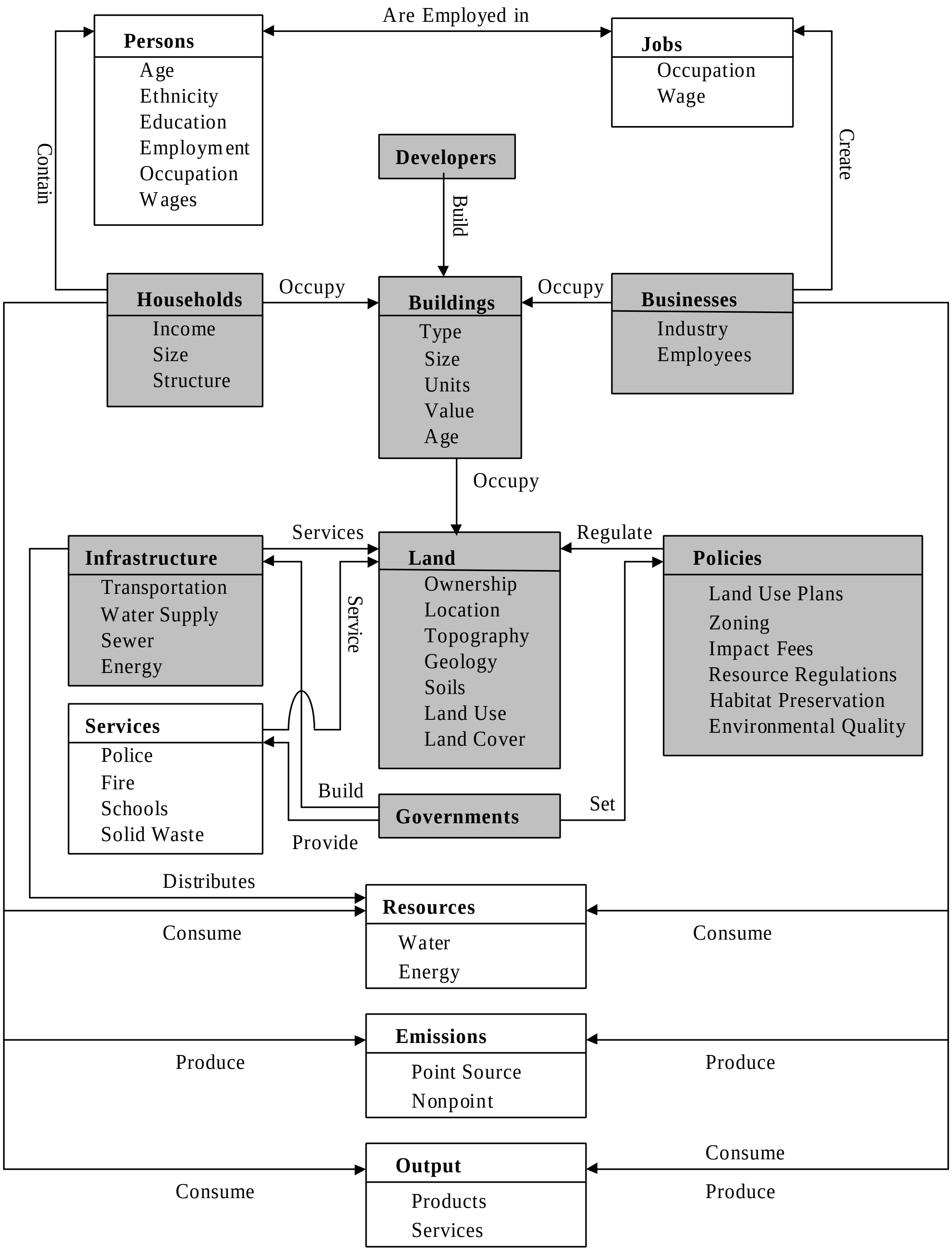
The objective of developing a modular framework that could be extended to incorporate additional aspects of the land use-transportation-environment web led to the conceptualization of the object structure of the model presented in Figure 2. This extended structure provides a blueprint for an integrated urban-environmental model system. The shaded components are those that have been implemented in the current modeling effort. The environmental and the labor market components represented by persons and jobs are under development as part of a regional urban-environmental modeling effort in the Puget Sound, but are beyond the scope of this paper. Other aspects, such as urban services, remain for future research.

Model Components

The behavior of the model system emerges from the behavior of objects and the methods used to change the attributes of existing objects, or to create new objects (e.g. buildings) or delete them. The following model components (methods) were designed to implement the model behavior:

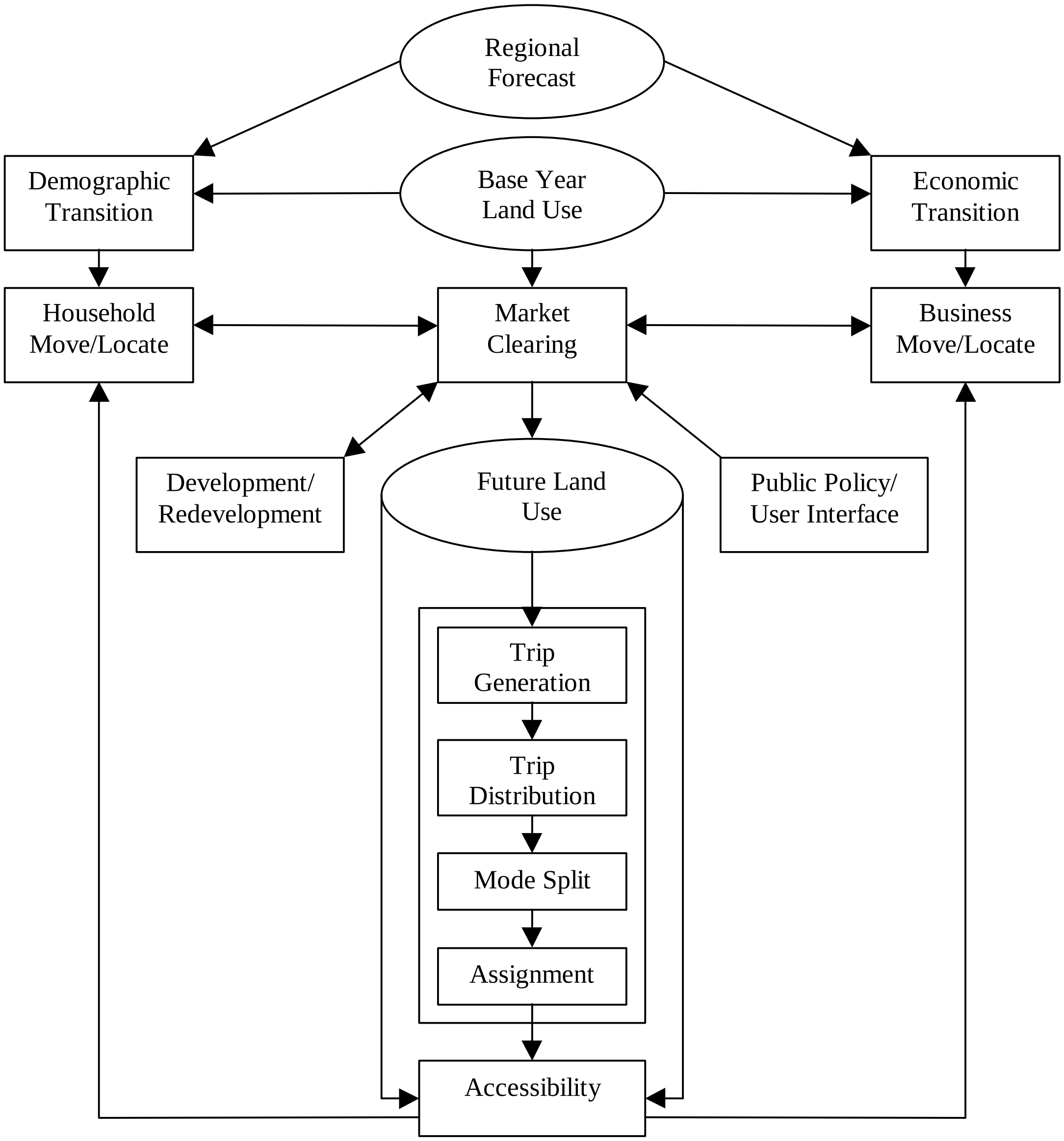
- Economic and Demographic Transition
- Mobility and Location Choice
- Land Development (and redevelopment)
- Market Clearing and Price Adjustment

Figure 2
Object Structure of UrbanSim



The flowchart in Figure 3 provides a more traditional representation of the model components and their interaction with each other and with a travel demand forecasting model (shaded), each of which are described briefly below.

Figure 3
UrbanSim Model Components



Exogenous 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, environmental constraints, and development impact fees. The user interacts with the model through the user interface to create scenarios that combine alternative packages of assumptions and exogenous inputs. The model is then executed using a given scenario, and the results of one or more scenarios can be examined and compared.

The model endogenously 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. Two components, demographic and economic transition, predict changes in the distribution of households and business by type (e.g. age, income, and businesses by industry) at the regional level, consistent with the aggregate control totals.

In the household mobility and location component, the 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. These choices are modeled in much the same way as mode choices of commuters, using multinomial or nested logit estimation techniques. In the business mobility and location module, 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.

In the development component, the 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 model simulates land market clearing by adjusting prices to reconcile the competing demands for locations and structures among households and businesses against the supply of space in each zone. The ratio of demand to supply in each zone for each type of space (housing and commercial structures by type) induces price adjustments for these structures. The adjusted prices produce new market signals to demanders in the subsequent year, thereby influencing preferences for zones and building types.

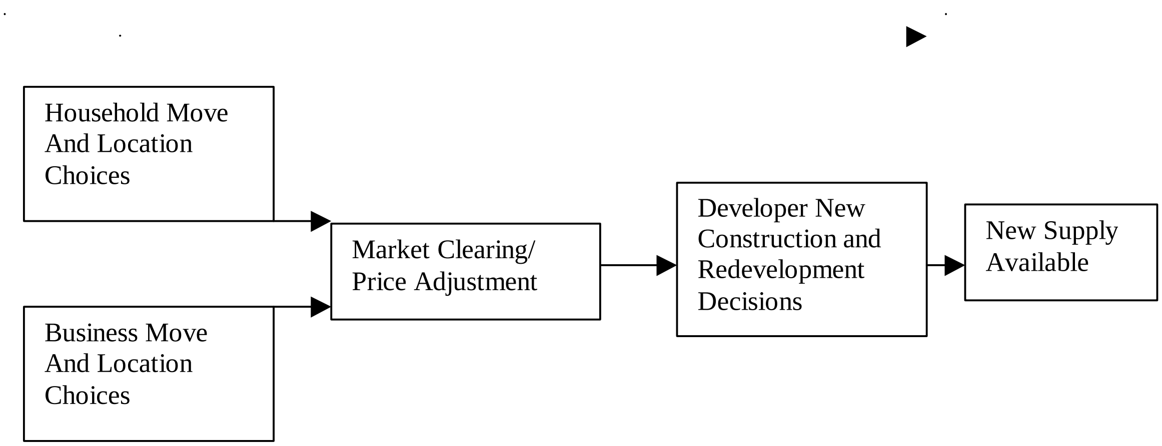
These interactions of households, businesses, developers, and governments produce outcomes representing the distribution of population and employment, as well as the prices, uses, and density of land development. These results are written out for any desired year that the travel models will be run. The data are fed into the traditional four-step travel models to produce new travel times, costs and patterns by mode. The analysis then uses these travel times to compute new accessibility indices in subsequent years, until the travel models are run for the next target year.

Temporal Dynamics

The model is based on a one-year timetable, which has several advantages. First, many of the actions modeled take place over durations of less than or approximately one year, including household and business location changes. Longer time frame actions, such as the introduction of major transportation system changes, are handled by introducing them in a particular year, from which time the model can account for the influence of this change over subsequent years. Figure 4 illustrates these dynamics.

Households and businesses are assumed to be price takers, as are developers. The implication of this assumption for the temporal dynamics of the model is that with a one-year increment, the model adjusts prices once each year. This occurs after computing the total demand for each location and building type within the location choice components of the model, and before developers estimate profitability of alternative construction projects. Developers then undertake new construction and redevelopment based on current market information, including current demand, and priced as adjusted to reflect the current period supply and demand. New construction then becomes available at the beginning of the next year, for new and moving businesses and households. Land development decisions are presently assumed to occur within one year, although multi-year construction timetables for large construction projects would be more realistic, and will be implemented in planned enhancements to the model.

Figure 4
Temporal Dynamics



Spatial Representation

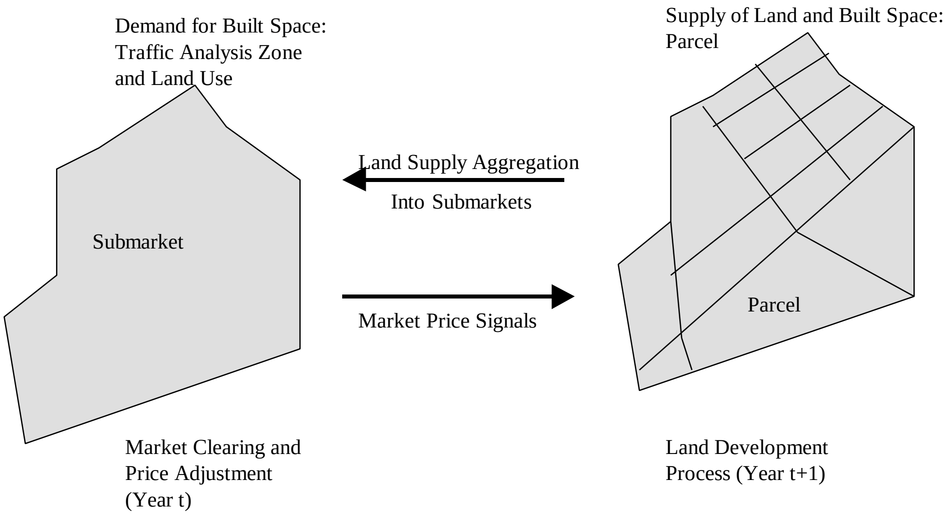
The supply of land has been represented at a geographic level of the land ownership parcel, which lends itself to analysis from the perspective of the land developer, that must acquire land one parcel at a time, and makes development decisions based on the attributes of the parcel. These attributes include any governmental restrictions on its potential use, as dictated in the comprehensive land use plan or through environmental regulations on development in environmentally sensitive lands.

Land ownership parcels are subdivided for analysis if intersected by boundaries such as floodplains, wetlands, areas of high slope, or other environmental features which are to be regulated in the land development process. The creation of the land supply inventory relies on the availability of parcel data and environmental boundaries in a Geographic Information System format, so they can be geographically overlaid and intersected.

To the author's knowledge, this modeling effort represents the first time that a land use model has been developed using parcel-level data. The California Urban Futures Model (Landis 1994, 1995) shares a similar approach to integrating land supply attributes with a GIS for modeling the land supply process, but does not use parcel-level data. Also, as noted by Landis, it does not represent households and businesses and their demands for development, nor does it integrate travel behavior or market behavior in the form of prices.

The demand for housing and commercial buildings has been initially represented at a more aggregate level than the individual land parcel, based on the conception of distinct submarkets defined by small-area boundaries and by housing types and non-residential building types. These submarkets are also the basis for the market interaction of supply and demand, through processes of market clearing and price adjustment. For convenience and consistency, the spatial extent of the submarkets has initially been defined to be contiguous with the zonal system used in the travel demand models. The spatial configuration of the demand and supply sides of the model are shown in Figure 2.

Figure 2:
Spatial Configuration of Land Market



Integration with Travel Demand Models

UrbanSim interfaces with travel forecasting models used by Metropolitan Planning Organizations to account for changes in the transportation system, and reflects these through accessibility indices in the model. Travel accessibility for households to employment and shopping, and for businesses to labor market and other business activity, are captured in the form of accessibility indices. The computation of these accessibility indices combines the distribution of opportunities (e.g. shopping) at each zonal destination, and the composite travel utility for reaching these destinations. The spatial distribution of activities is maintained endogenously by UrbanSim, whereas the composite utility of travel between zones is predicted by a separate travel demand model, the specifications of which vary significantly. 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[3]. The mode choice model in many of these models is based on a logit model formulation that allows the computation of a composite utility, or logsum, of all of the alternative modes connecting two zones. This composite utility has the advantage, for our purposes, of incorporating multiple modes of travel, and multiple attributes such as cost, time, and convenience.

Since this model is not of the monocentric or spatial interaction genre, in which the choice of workplace is exogenous and residential locations are chosen on the basis principally of commute to the city center or to a predetermined workplace, we deal with accessibility in a more general framework. Accessibility is considered a normal good, like other positive attributes of housing, which consumers place a positive economic value on. We therefore expect that consumers' value access to workplaces and shopping opportunities, among the many other attributes they consider in their housing preferences. Nor would all households respond to accessibility in the same way. Retired persons would be less influenced by accessibility to job opportunities than would working age households, for instance.

We operationalize the concept of accessibility for a given location as the distribution of opportunities weighted by the travel impedance or alternatively the utility of travel to those destinations. The utility of travel is operationalized as the composite utility across all modes of travel for each zone pair, obtained as the logsum of the mode choice for each origin-destination pair. The resulting access measure for each location, then is:

$$Access_i = \sum_{j}^{J} A_j e^{b\,L_{ij}}$$

where

A_j is the quantity of activity in location j

L_{ij} is composite utility, or logsum (for one car households), from location i to j.

β is the utility scaling parameter, initially set to 1

The computation of accessibility indices for each zone is implemented as a travel utility-weighted total of the activity in each destination zone. The activity levels are updated annually by the model, so that although the travel times and utilities remain constant until the subsequent travel model run, the accessibility indices change based on the distribution of activities. Major transportation improvements are likely to be fairly discrete in time, such as the opening of a new section of a freeway. The schedule for interfacing the travel

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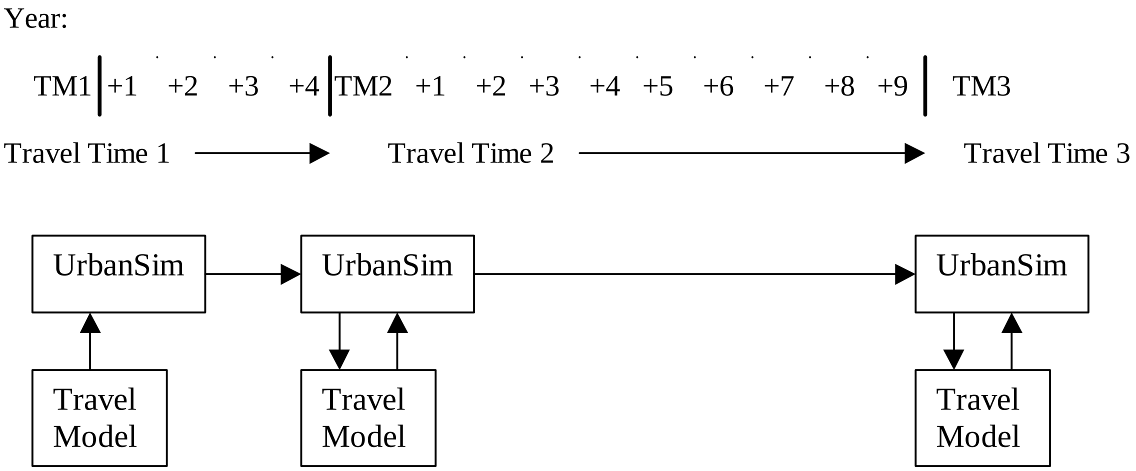
[3] New travel demand models are under development that use an activity-based approach to modeling travel behavior, and in the long-run, provide an avenue to more fully integrate the land use and travel models. Work is underway to integrate UrbanSim with a new generation activity-based travel model in Honolulu.

models, then, is likely to be dictated by changes in the transport system. The travel models can be run and interfaced with UrbanSim as needed, even annually.

Figure 3
Land Use-Travel Model Interaction



Note that the form of accessibility that is measured using these indices is what has been dubbed ‘regional accessibility’ (Handy). More localized accessibility, such as that motivated by concerns regarding the potential impact of new urbanist design on pedestrian travel, require a different approach. In practical terms, the major constraint on current travel models appears to be the reliance on a zonal system that is too coarse for pedestrian-scale analysis, since it is geared toward the analysis of the transport networks dominated by vehicular traffic, and many zones are far larger than the ¼ mile scale more relevant to the pedestrian. This constraint impacts the current design of UrbanSim, as well, since it uses traffic analysis zones to define submarkets, and is linked to existing travel models that do not incorporate pedestrian scale analysis. Further work to support pedestrian scale analysis within UrbanSim is now underway.

Relationship to Other Research in Urban Modeling

Reviews of the literature in urban land use modeling are in ample supply, with contributions by Anas (1982), Harris (1985), Kain (1987), Paulley and Webster (1991), Southworth (1995), and Wegener (1995), among others. This paper does not, therefore, attempt to systematically review the literature, but presents the UrbanSim model within a context of existing work in operational land use modeling. Further description of the theoretical basis of the model, and its relationship to prior research, and complete model specifications are provided elsewhere (Waddell, 1998a), as they lie beyond the scope of this paper. The following is intended to provide a brief overview of the theoretical foundation of the model in order to provide a meaningful context for the model.

We follow in our theoretical development a substantial body of research in urban land markets. Of particular relevance to this model are two streams of research that have recently been bridged. The first developed a theory of urban land markets using a bid rent approach, and the second focuses on consumer choices among discrete location alternatives based on the utility provided by these alternatives. Ellickson (1981) provides a useful starting point for this discussion, by developing a logit model of the property auction process based on the bid rent function rather than the utility function. Essentially, this approach focused on the landowner's problem of selling to the highest bidder, which is the consumer making the highest bid. It differs from the majority of logit models of residential choice, which focus on the consumer's problem of choosing among properties based on maximizing their utility function. Essentially these approaches represent the two sides of the auction: the buyer's perspective and the seller's. Martinez (1992) extended Ellickson's work by developing a 'bid-choice' model that dealt with both sides of the auction simultaneously, through a nested logit formulation in which the higher level of the model represented the consumer's choice among properties, and the lower level represented the landowner's choice among bidders. Under equilibrium assumptions, Martinez showed the consistency of these approaches.

At the core of the model developed by Martinez is a formulation based on consumer surplus, defined as the willingness to pay for an alternative less the market price of that alternative. It has a simple and intuitive interpretation: a consumer is happiest with an alternative that maximizes the difference between what they are willing to pay and what they must pay based on the market price.

Martinez (1992) derives a multinomial logit model predicting the probability that a consumer h will choose lot i:

$$P_{i|h} = \frac{e^{m(\Theta_{hi} - p_i)}}{\sum_j e^{m(\Theta_{hj} - p_j)}}$$

where:

Θ_{hi} is the willingness of consumer h to pay for lot i

p_i is the market price of lot i

The probability of choosing alternative i then is a function of the relative consumer surplus of the alternatives:

$$CS_{hi} = \Theta_{hi} - p_i$$

Martinez adopts an equilibrium formulation in which the market price is endogenous and determined by the highest bid for each site among all consumers. This interpretation is founded on the view of land as a quasi-unique commodity in fixed supply, so that demand dictates price. It does not, apparently, represent buildings as part of supply, with either short or long-term adjustment in supply interacting with demand to influence prices.

A third relevant line of research in residential location, originating in geography and sociology, is on residential mobility. These models include work that focuses on the household characteristics and on dissatisfaction, or push factors, inducing mobility. Research in this vein includes that of Wolpert (1965), work by Brown and Moore (1970) on separating the decision to move and the decision to search, and Speare *et al* (1975). Economists formalized these models as disequilibrium models of housing expenditure, for example by Hanushek and Quigley (1978). Onaka (1983) has formulated a variation of the housing disequilibrium model using hedonic theory. More recent work has linked the mobility and location choice approaches. DePalma and Ben-Akiva (1981) developed a dynamic model of residential location based on household choice and transactions costs. Van Lierop and Rima (1982), Onaka and Clark (1983), Clark and Onaka (1985), and Kain and Apgar (1987) also developed two stage models of the decision to move and the choice of location.

The UrbanSim model structure and theory integrate and extend elements of the consumer surplus approach taken by Martinez with the dynamic mobility and location choice modeling approach. This is embedded within a larger simulation model that deals with land market clearing, land development, and aggregate metropolitan changes in the distribution of households and businesses by type.

UrbanSim differs significantly from several existing operational modeling approaches, including the spatial-interaction DRAM/EMPAL models developed by Putman (1983); the spatially-disaggregated 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; 1998), and the CATLAS (and later METROSIM) model developed by Anas (1982). These models are discussed in detail in the reviews cited at the beginning of this section, and are not elaborated on here. Compared with these models, UrbanSim is unique in the following ways:

- Dynamic structure of year to year evolution of urban development (as opposed to long-run equilibrium assumptions);
- Explicit representation of move and location choices;
- Explicit representation and accounting of land, structures and occupants, and market prices;
- Parcel-level microsimulation of land development and redevelopment;
- Disaggregation of the location choice to the level of traffic analysis zones;
- Substantial disaggregation of household and business types;
- Integration with existing travel models;
- Explicit input of public sector choices as policy scenarios.

Model Specification

The preceding discussion motivated and described the overall design of the UrbanSim model. We turn now to a brief elaboration of the specification of the principal model components that are of most immediate concern to growth management analysis:

business location, household location, market clearing, and land development. Mobility choice is

Business Mobility and Location

Business Bid Function

The bid function is specified for each business type based on zone characteristics and building types.

$$B_{bl} = f(Z, S)$$

where Z is an array of zone characteristics

S is an array of dummy variables for space types

The variables included in the business bid price function are drawn from the literature in urban economics. We would expect that accessibility to population, particularly high-income population, increases bids for retail and service businesses. We also expect that two forms of agglomeration economies influence bids: localization economies and inter-industry linkages.

Localization economies represent positive externalities associated with locations that have other firms in the same industry nearby. The basis for the attraction may be some combination of a shared skilled labor pool, comparison shopping in the case of retail, co-location at a site with highly desirable characteristics, or other factors that cause the costs of production to decline as greater concentration of businesses in the industry occurs. The classic example of localization economies is Silicon Valley. Inter-industry linkages refer to agglomeration economies associated with location at a site that has greater access to businesses in strategically related, but different, industries. Examples would include manufacturers locating near concentrations of suppliers in different industries, or distribution companies locating where they can readily service retail outlets.

One complication in measuring localization economies and inter-industry linkages is determining the relevant distance for agglomeration economies to influence location choices. At one level, agglomeration economies are likely to affect business location choices between states, or between metropolitan areas within a state. Within a single metropolitan area, we are concerned more with agglomeration economies at a scale relevant to the formation of employment centers. This scale of effect is likely to be larger than a single traffic analysis zone, the unit of analysis in this application. We therefore include variables representing the activity within an industry both within a zone, and separately for access to the activity weighted by the composite utility of travel between zones (logsum). By including the quantity of employment within a zone, we would introduce an artifact of zone size that would lead to arbitrary results were we to split zones, so we use a gross density of employment in the industry to correct for this.

Age of buildings is included in the model to estimate the influence of age depreciation of commercial buildings, with the expectation that businesses prefer newer buildings and discount their bids for older ones. This reflects the deterioration of older buildings, changing architecture, and preferences, as was the case in residential housing. There is the possibility that significant renovation will make the actual year built less relevant, and we would expect that this would dampen the coefficient for age depreciation. We do not at this point attempt to model maintenance and renovation investments and the quality of buildings.

Density, the inverse of lot size, is included in the business bid price model. We expect businesses, like households, to reveal different preferences for land based on their production functions and the role of amenities such as green space and parking area. As manufacturing production continues to shift to more horizontal, land-intensive technology, we expect the discounting for density to be relatively high. Retail, with its concentration in shopping strips and malls, still requires substantial surface land for parking, and is likely to discount bids less for density. Service firms, which in the traditional urban economics models of bid-rent generally outbid other firms for sites with higher accessibility, land cost, and density, we expect to discount density the least.

We might expect that certain sectors, particularly retail, show some preference for locations near a major highway, and are willing to bid higher for those locations. Note that we measure the presence of a highway as a Boolean variable based on its presence within or at the boundary of a zone. There may be some measurement error associated with both the zonal level of aggregation, as well as the functional classification of roadway segments as highways. We also test for the residual influence of classic monocentric model, measured by travel time to the CBD, after controlling for population access and agglomeration economies. We expect that the CBD accessibility influence will be insignificant or reverse of the traditional monocentric model, after accounting for these other effects.

Finally, we test for market supply effects on bids by including the size of the available nonresidential stock of the appropriate type of building space in the zone. If we were truly observing the maximum willingness to pay, then a supply effect should not be present. Since we expect that we are observing a bid that matches the market price, and is below the willingness to pay, then higher market supply might well be expected to add competition and thus lower the bids offered, and therefore the exchange price. This market supply effect is different from the other effects included in the model, since it does not represent an attribute that influences demand. We therefore use the variable in the estimation step to remove the potential bias on other variables that might be encountered by excluding it. In the subsequent step in which we use the fitted bid price function to predict bids, however, we drop this term. This will generate bids that respond more closely to underlying consumer preferences, and leaves the market price adjustment external to the formation of bids. We include a market supply effect measured as the log of the square footage of built space in the zone, of the type chosen by the business. Note that this measure adds an artifact of zone size that is arbitrary. Removal of the size term influenced other coefficients in the model to some degree in the residential case, and to a larger degree in the nonresidential case.

Calibration of the model is based on a geocoded establishment file (matched to the parcel file to link employment by type to land use by type). Movers identified in the file are used as the sample for estimating location choice, since their choices have been expressed under relatively current conditions. As in the residential location choice model, the application of the model produces demand by each employment type for space of each nonresidential type, by zone. The total demand for space by zone by type is computed by summing demand across employment types and space types.

Business Building Type and Location Choice

In this component of the model, we predict the probability that a business that is either new (from the transition component), or has decided to move within the region (from the mobility component), will choose a particular combination of location and building type (landuse). The joint multinomial logit specification predicts the joint probability of building type and location.

$$P_{bl} = \frac{e^{V_{bl}}}{\sum_{b'l'} e^{V_{b'l'}}}$$

where P_{bl} is the joint probability of choosing location l and building type b

The systematic component of the utility is specified as the consumer surplus of each alternative, and a size term to account for the aggregation of alternatives. The consumer surplus is further defined as the bid for an alternative less its market price, which is taken as exogenous to the individual firm.

Household Mobility and Location

Residential Bid Function

The bid function is specified for each household type based on zone characteristics and housing types.

$$B_{bl} = f(Z, S)$$

where Z is an array of zone characteristics

S is an array of dummy variables for housing types

We estimate bid functions for households stratified by income level and by the presence of children, a key life cycle characteristic. Once the bid price functions have been estimated, the bid price equation is used to generate bids for each of the alternatives in the choice set, to estimate the consumer surplus for each alternative, and ultimately to predict the location choice probability.

The variables included in the household bid function, and their theoretical justification, are discussed below. The variables are drawn from the literature in urban economics, urban geography, and urban sociology. An initial feature of the model specification is the incorporation of the classical urban economic trade-off between transportation and land cost. This has been generalized to account not only for travel time to the classical monocentric center, the CBD, but also to more generalized access to employment opportunities and to shopping. These accessibilities to work and shopping are measured by weighting the opportunities at each destination zone with a composite utility of travel across all modes to the destination, based on the logsum from the mode choice travel model.

These measures of accessibility should negate the traditional pull of the CBD, and for some population segments, potentially reverse it. In addition to these accessibility variables, we include in the model a net building density, to measure the input-substitution effect of land and capital. To the extent that land near high accessibility locations is bid up in price, we should expect that builders will substitute capital for land and build at higher densities. Consumers for whom land is a more important amenity will choose larger lot housing with less accessibility, and the converse should hold for households that value accessibility more than land, such as higher income childless households.

The age of housing is considered for two reasons. First, we should expect that housing depreciates with age, since the expected life of a building is finite, and a consistent stream of maintenance investments are required to slow the deterioration of the structure once it is built. Second, due to changing architectural styles, amenities, and tastes, we should expect that the wealthiest households prefer newer housing, all else being equal. The exception to this pattern is likely to be older, architecturally interesting and high quality housing in historically wealthy neighborhoods. The preference for these alternatives could be accommodated through a combination of nonlinear or dummy variable treatment for this type of housing and neighborhood.

A related hypothesis from urban economics is that since housing is considered a normal good, and therefore has a positive income elasticity of demand. This implies that as incomes rise, households will spend a portion of the gains in income to purchase housing that is more expensive, and which provides more amenities (structural and neighborhood) than their prior dwelling. A similar hypothesis is articulated in urban sociology (see for example, Massey, 1992), in which upward social mobility is associated with spatial proximity to higher status households. Both of these hypotheses would predict that households of any given income level would prefer, all else being equal, to locate in neighborhoods that have higher average incomes.

The age hypothesis and the two income-related hypotheses are consistent with the housing filtering model, which explains the dynamic of new housing construction for wealthy households that sets in motion a chain of vacancies. The vacancy chain causes households to move into higher status neighborhoods than the ones they leave, and housing units to be successively occupied by lower and lower status occupants. At the end of the vacancy chain, in the least desirable housing stock and the least desirable neighborhoods, there is insufficient demand to sustain the housing stock and vacancies go unsatisfied, leading ultimately to housing abandonment. We include in the model an age depreciation variable, along with a neighborhood income composition set of variables, to collectively test the housing filtering and related hypotheses.

Housing type is included in the model as a set of dummy variables for alternative housing types, with single family housing excluded as a base of comparison. Residential housing with two to four units (duplex, triplex, and quadplex), and multi-family housing, are expected to be significantly discounted in bid prices, since they are likely to have smaller living space and fewer amenities than single family housing.

Given the stratification of households into consumer market segments based on income and the presence of children, we test for compositional effects not only of income, but also of the proportion of households with children in a neighborhood. We expect that households with children would be willing to pay more for a house in a neighborhood with more children, all else being equal, than a similar income household without children.

Among the amenities that households prefer are attributes of the land use mix within the neighborhood. It is likely that residential land use, as a proxy for land uses that are compatible with residential use, positively influences housing bids. On the other hand, industrial land use, as a proxy for less desirable land use characteristics, would lower bids.

The size variable is measured by the log of the number of available housing units of a particular type in the zone. As in the nonresidential case, this market supply effect is included to more purely measure the preference components of the bid price function, and is excluded from the formation of bids used in the computation of consumer surplus.

The model is calibrated using a random sample of alternative locations, which has been shown to provide consistent estimates of the coefficients. In application for forecasting, the predictive equation will be applied to all alternatives for each household type being allocated, producing the demand for housing of each type and tenure in each zone. All of the independent variables will be updated in each forecast year increment, based on results of the prior period iteration of the model set. Total housing demand in each zone is computed by summing demand across household types.

Household Location and Housing Type Choice

In this component of the model, in parallel to the business location component, we predict the probability that a household that is either new (from the transition component), or has decided to move within the region (from the mobility component), will choose a particular combination of location and housing type (landuse). As before, the form of the model can be specified as either nested logit or as joint multinomial logit. As with business location, the joint multinomial logit specification predicts the joint probability of housing type and location.

$$P_{hl} = \frac{e^{V_{hl}}}{\sum_{h'l'} e^{V_{h'l'}}}$$

where P_{hl} is the joint probability of choosing location l and housing type h.

The systematic component of the utility is specified as the consumer surplus of each alternative, and a size term to account for the aggregation of alternatives. The consumer surplus is further defined as the bid for an alternative less its market price, which is taken as exogenous to the individual household.

Market Clearing and Land Price Adjustment

The land market clearing is a component of the model system that reconciles demand for land from households and establishments with each other, and with the available land supply in every year simulated. It handles the assignment of moving businesses and households to their highest utility alternative that is available, and adjusts land prices based on the demand and supply in each zone. Since prices enter the location choice utility functions for businesses and households, an adjustment in prices will alter their location preferences, causing higher price alternatives to become more likely to be chosen by occupants that have lower price elasticity of demand, all else being equal. Similarly, any adjustment in land prices alters the preferences of developers to build new construction by type of space, and the density of the construction.

Once households and businesses have evaluated all the available alternatives, and expressed their preferences (through a probability prediction from the location choice models), the simulation attempts to place households and businesses into buildings in proportion to their predicted probabilities. Building objects that become full during this operation are removed from the remainder of the allocation process, and households and businesses that are unable to locate into their highest utility building are forced to accept their next highest utility alternative. This process iterates until all businesses and households are located in buildings and houses.

The market clearing mechanism, then, is not strictly through a full equilibrium price adjustment, in which perfect information exists, and transaction costs are zero, so that prices on all buildings at each location adjust to the equilibrium solution that clears the market. Rather, the solution is based on an expectation of incomplete information and nontrivial transactions and search costs, so that movers obtain the highest satisfactory location that is available, and prices respond at the end of the year to the balance of demand and supply at each location.

Once the market assignment is completed, the information generated by the market simulation about the relative demand and supply of each building type at each location is used to update prices. The magnitude of the price adjustment is based on the ratio of the total demand for each building object to the existing supply of space in the building object.

We make the following assumptions:

1. Households and businesses respond to prices of housing and nonresidential space at the start of the current year, if they are moving in this year.

2. Developers respond to current market prices, after they have been adjusted to account for the current year demand and supply

3. Households, businesses, and developers are all price-takers, and market adjustments are made by the market in response to aggregate demand and supply relationships.

4. Location preferences are capitalized into land values. Building value reflects building replacement costs only, and can include variations in development costs due to terrain, environmental constraints or development policy. The market price per housing unit or per square foot of nonresidential space is the sum of land and building value.

5. There is a normal vacancy rate, above which the market triggers an upward adjustment in land prices, and below which it triggers a decline. Such price adjustments will occur in proportion to the ratio of demand to supply for each building type at each location.

Based on these assumptions, consistent with urban economic theory, the price adjustment mechanism causes an adjustment in the location preferences of businesses and households in the following year. Developers respond to current prices by maximizing the profitability of construction, subject to the constraints of land supply and development policy. The supply of housing and commercial space consumed in any iteration comes from existing vacant structures plus any new construction and redevelopment of structures that occurred in the most recent period. New construction in a forecast interval can include committed, proposed, and potential development projects identified by the user as exogenous policy input.

The form of the price adjustment is:

$$P_{lbt} = P_{lbt-1}\left[\frac{\left(1+a_{b}-V_{lbt}\right)+\ l\left(1+a_{b}-V_{bt}\right)}{1+\ l}\right]^{b}$$

where

P_{lbt} is the land price of building type b in location l in year t

P_{lbt-1} is the previous year closing land price for the same building and location

V_{lbt} is the current vacancy rate for space in the building type and location l

α_b is the normal vacancy rate for building type b

$\beta$is a scaling parameter for the price adjustment, initially set to 1

? is a parameter for weighting the regional and zonal influence

This functional form is a modification of the original form in the prototype version of UrbanSim, which used the relationship of latent demand to actual supply in each zone for each building type. Early testing revealed that the prior specification produced unrealistic results, and local zonal conditions were not influenced by overall market conditions. This led to the revision of the specification to one based on the vacancy rate conditions in the zone and the region. Further testing of the revised functional form suggests that is produces plausible responses to changing market conditions. Further testing of this form is underway.

Vacant Land Price Adjustment

Since vacant land price is a key determinant of the profitability of alternative development outcomes on each vacant parcel (entering the cost side of the profit equation) the model must update vacant land prices as urban development proceeds and the prices of developed land change around each vacant parcel. We would expect that vacant land prices will adjust in relationship to developed land prices in a local area as a result of land speculation. Speculators purchase vacant land and hold the land until the land price increases as the opportunities for developing the land increase with the encroachment of urban land development.

Vacant land prices are adjusted by the weighted average of the price adjustments (in the current year) of each of the building types in a location. After the location of businesses and households triggers a market adjustment in land prices for each building type, these price adjustments are applied to the vacant parcels in a zone in proportion to the acreage of land in each building type.

Land development and Redevelopment

Aggregate Demand

The aggregate demand for built space of each building type in each period is estimated as an initial step in the process of land development and redevelopment. The model uses profitability as an indicator of the relative probability that specific projects will be built, but governs the aggregate quantity of construction by the estimate of aggregate demand and its change from one year to the next. The estimation of aggregate demand follows the current vacancy rate for each property market, and triggers new development when the vacancy rate falls below the normal, or threshold, vacancy rate.

$$D_{bt} - D_{bt-1} = \left((a_b - V_{bt-1}) S_{bt-1} \right)^b$$

where

$D_{bt} - D_{bt-1}$ is the growth in aggregate demand for building type b

a_b is the normal market vacancy rate for building type b

V_{bt-1} is the actual vacancy rate in t-1 for building type b

S_{bt-1} is the total supply of space in building type b in t-1

ß is a scaling parameter

Profitability of Development

The land development component of UrbanSim simulates the process of land development and redevelopment into the urban land uses being modeled. The core of the model is a profit maximization calculation based on the costs and expected revenues from development of alternative parcels into allowable developed uses. The developer component of the model is the most directly influenced by local policies such as the comprehensive plan, density constraints, the Urban Growth Boundary, environmental constraints, and development impact fees or other development costs dictated by local governments. Due to the complexities of this module, the current implementation can only be partly calibrated statistically. The model applies the logic of profit maximization to user inputs regarding development constraints and costs and the available parcel data for both vacant and already developed parcels to microsimulate the behavior of developers development and redevelopment behavior. The approach taken in this model component is conceptually very similar to the first implementation of the California Urban Futures Model (Landis, 1994). The major difference in the profit calculation is that the CUF model did not incorporate expected revenue into the profit calculation, so profit was affected only by development costs and not by changes in consumer demand.

Developers are assumed to be myopic in their expectations, making predictions about expected profits from development based on current market conditions. This assumption of imperfect information is entirely consistent with the familiar cycle of real estate speculation, overbuilding, and bust. Over longer forecasting horizons, however, we expect the model to predict development behavior without the short-run volatility present in actual real estate markets.

A key assumption of the model is the standard economic assumption that the value of location is capitalized fully into land value. Land values absorb the value of location, meaning that as demand increases for a certain location, since land is in fixed supply, the price of the land at that location increases. Conversely, as demand for a location declines, land prices at that location decline as well. The improvement values on existing development are assumed not to be affected by these land price fluctuations, though land values would influence developers decisions of what and where to build new structures or redevelop existing ones. Improvement values, then, are based strictly on replacement value, and do not vary spatially.

For new development, developers are assumed to make profitability calculations on converting every vacant parcel to each of the building types (land uses) for the parcel that is allowed within local policy constraints. These combinations of parcels and alternative developments on them, or development ‘projects’, are compared in terms of their profitability to the developer. The profit calculation involves revenue expectations based on current market demand and prices, and on the costs of developing each specific parcel into the development project being evaluated. In short, the profit expectations are influenced both by changing market demand, and by factors influencing development costs. Developers are assumed to build development projects in order of profitability, and to continue building profitable projects until the demand for additional space in the land use is satisfied. The vacancy rate is used as the threshold to trigger new development, since development profits are assumed to go to zero as the vacancy rate reaches the ‘normal’ vacancy rate, and developers are assumed to continue to build until the zero profit threshold is reached[4].

For redevelopment, we assume that developer will examine the potential redevelopment of parcels that are under-utilized, in the sense that the ratio of the value of the improvements on a parcel to its land value is very low. This would typically occur where there may have been low cost construction on certain parcels in an area that is now experiencing upward development pressure, driving land prices up. The combination of depreciated improvements that were perhaps of low value to begin with, and rising land costs, would trigger the assessment of these parcels by developers for potential redevelopment. We assume that redevelopment competes directly with new development on vacant land (which includes infill). This means that a developer makes a profit-maximizing choice among the development options, including redevelopment, and will only redevelop a parcel if its total development profitability, including the costs of the improvements and their demolition, fall above the profitability of other available vacant parcels. This is most likely to occur under fairly tight market conditions, such as the imposition of fairly strict growth management policies. A tightly drawn and enforced Urban Growth Boundary, for example, in a metropolitan area with high rates of economic growth, would likely cause land prices to rise rapidly, as the supply of vacant land shrinks, and demand for new development increases. In such a context, it is substantially more likely that a sizable fraction of the currently developed parcels are sufficiently under-utilized to compete favorably for development with some fraction of the remaining vacant parcels.

We can specify the developer decision as one of converting land from existing status to one of a finite set of alternative land uses at a particular density, based on the expected profit of the conversion.

$$\widehat{\Pi}_i(lb) = \widehat{R}_{lb}Q_{ib} - L_i A_i - H_b Q_{ib} - S_{lb}Q_{ib} - I_{ib'}Q_{ib'} - D_{ib'}Q_{ib'}$$

where:

$\widehat{\Pi}_i(lb)$ is the expected profit from developing parcel i in location l into building type b

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[4] A further refinement of the model would incorporate a cost of capital component in the profitability calculation, which would allow profit to be influenced by interest rates and access to capital. As widely observed in the 1980’s real estate boom, the cost of capital dropped due to a combination of factors, making real estate development profitable to developers at levels well above normal, sustainable, market vacancy rates. This refinement lies beyond the current model scope, however.

$\widehat{R}_{lb}Q_{ib}$ is the expected revenue from selling the project to household or business consumers

$L_i A_i$ is the land cost of parcel i (land cost per acre times acres)

$H_b Q_{ib}$ is the 'hard' construction cost of the development project, equal to its replacement cost

$S_{lb}Q_{ib}$ is the 'soft' construction cost of developing the project, inclusive of all development fees

$I_{ib'}Q_{ib'}$ is the cost of existing improvements on parcel i if it is being redeveloped

$D_{ib'}Q_{ib'}$ is the demolition cost for any improvements on parcel i if it is being redeveloped

The expected revenue is based on the current market price for space of building type b in location l:

$$\widehat{R}_{lb} = P_{lb}$$

If no development of type b currently exists in location l, and therefore the current market price is undefined, then the average current market value of buildings type b from locations within 5 minutes is used as the estimate of expected revenue instead. In the event that no buildings of type b are encountered in zones within 5 minutes, then the average current market value from the region is used.

Density

The quantity of construction, Q_{ib}, is a function of the size of the parcel being evaluated and the density of construction. The density at which new construction occurs is predicted to be responsive to land prices, with higher land prices prompting capital/land substitution by developers. As land prices increase, we would expect developers to build at higher densities. In markets with a supply of vacant land that is low relative to the demand generated by economic growth, vacant land prices should increase, sending an economic signal to developers to increase density.

The density on which the expected profit of each development project is computed, then, is:

$$\Phi_{lb} = \boldsymbol{a}_b + \boldsymbol{b}_b \ln(P_{lb})$$

where

Φ_{ib} is the density of parcels in location l and building type b

P_{lb} is the land price per acre in location l for building type b

Hard Construction Costs

Hard construction costs are typically the largest component of the development costs of a project. These are the labor and material costs of actually building the structure, not including costs of urban service extensions, and are commonly referred to as replacement costs for a building structure. There is considerable variance in construction costs across different building types, and even within the same building type. We assume, in the initial version of the model, that improvement costs do not vary within a building type. Hard construction costs may be estimated by building type from assessed improvement values, from local construction industry sources, or other possible sources.

Soft Construction Costs

Soft construction costs include a variety of fees determined by local governments, which are assumed by the developer, and, depending on the site, could play a significant role in determining the profitability of developing. While the detailed manner in which such costs are levied vary greatly across municipalities, such fees can be classified into three common categories: development and impact fees, service extension costs, and building permit fees. Because of the tremendous variability in the way such fees are implemented, the model adopts a simplification that collapses all such costs into an average 'soft cost' applicable to each building type, and a soft cost adjustment factor that allows this cost to be adjusted up or down by location (zone) based on such factors as the level of urban service extension that would be required for development at each location.

Development and Impact Fees

Impact fees (also commonly referred to as development impact fees, system development charges, and the capital expansion component of connection charges) are assessments levied on new development to help pay for the construction of off-site capital improvements that benefit the contributing development. By far the most common fees charged are water and sewer facilities. After these utilities, roadways are the next most common charge, and after highways, the frequency of use of other fees drops markedly (Nicholas, Nelson et al. 1991) but may include improvements such as parks, libraries, police and fire facilities, hospitals, schools, solid waste.

Impact fee methodologies that reflect the actual cost of providing services based on location provide an incentive for development locate in areas with already facilities or where it is less costly to serve (Nelson, Duncan et al. 1995). Jurisdictions can use impact fees as a positive growth management tool by encouraging growth (through the use of lower fees) in areas already served by the public facilities and discouraging growth (through the use of higher fees) in areas without infrastructure. Currently, 18 states have adopted impact fee enabling acts and, because they are a derivative police power of the state given to municipalities, the nature, reason, and magnitude of the impact fees differ considerably between communities. Typically, fees are assessed using a schedule that sets forth the charge per dwelling unit or per 1,000 square feet of non-residential floor space. For example, a "typical" impact fee (to cover transportation, stormwater, parks, wastewater) for a single family dwelling unit may be on the order of $3,000 to $4,000 (Nicholas, Nelson et al. 1991; City of Eugene 1997).

Service Extension Costs

Local governments may also charge service extension costs for the development to be served by the public water, wastewater, stormwater, electrical and/or other already existing systems. While service extension costs may be commonly grouped with, or referred to as, impact fees, service costs are different in two respects. First, they are usually restricted to utilities such as plumbing, electrical, or city light, where as impact fees may include schools, file, police, etc. More importantly, service extension costs are charged for hooking into *existing* utility systems as opposed to impact fees which are assessed for new services.

Service extension costs, however, vary greatly both *between* and *within* municipalities based on specific site conditions of the parcel or the municipality's fiscal structure, current impact fees, or development objectives. The magnitude of extension costs may depend not only on the size and type of construction, but also on the ease by which a particular service can be accessed from the development site. In Eugene, a 20,000 square foot retail building accrued less than $3,000 in electrical, plumbing and mechanical type charges (excluding impact fees).

Building/Permit/Plan Review Fees

Building, permit, or plan review fees are charged by municipalities to cover the application, review and inspection process associated with new construction. The development fee may consist of a permit fee and, where plans are routed for review, a separate plan review fee (e.g. conditional use permit, variance). Often, a significant portion of these fees are derived from a local schedule of rates based on total valuation of the development (using the same data and method for calculating hard construction costs). For example, 80 or 90 percent of the total fees charged for permit and/or plan review are based on the valuation of the structure, and other fees for such things as drainage, grading, or noise reduction may be charged separately.

Demolition Costs

To adequately account for the costs associated with redevelopment, where developers are replacing existing development with new development, it is necessary to account for costs associated the demolition of existing structures. These costs include the value of the buildings, since we assume that the developer must purchase the entire property and there is non-zero value in the improvements, as well as the cost to demolish and remove the structures.

Simulating Growth Management Strategies

Based on the preceding elaboration of the model specifications, we return to the application of the model system to simulating the effects of growth management strategies. The application of the model involves the development of scenarios of policy and infrastructure assumptions on which a model simulation will be based. To review, the following elements, or instruments of growth management, are currently feasible to test within such scenarios:

Urban Growth Boundary

The Urban Growth Boundary can be changed as a policy test, and the resulting changes in the distribution of population, employment, physical development, land values, and housing costs can be monitored. Moreover, the modification of the interpretation of the land use plan, or the imposition of density constraints, can be modified inside or outside the UGB for assessment.

Environmental Constraints (wetlands, floodplains, stream buffers, high slope areas)

Multiple geographic layers representing local environmental concerns can be incorporated into the model. In addition, the way that these affect development can be modified as a policy test. The regulation of development on these areas is through the modification of the maximum allowable density of development.

Comprehensive Land Use Plans (rules for development)

The comprehensive land use plan is used in the model to provide rules governing the conversion of individual land parcels into alternative urban land uses. Each land use plan designation can be assigned a set of allowable conversions to urban development types. One sensitivity test, then, would be to allow certain plan designations to allow conversion of parcels to more development types, thereby simulating a mixed-use policy. While each individual parcel will only be assigned a single use in the model as it is presently constructed, an area designated as mixed use will allow the model to simulate mixed use development among multiple parcels.

Minimum and Maximum Densities for each Land Use

While maximum densities, or minimum lot sizes, have been the staple of suburban zoning for decades, the potential use of minimum zoning as a policy instrument for growth management is an innovation supported by the model implementation. Effects on the profitability, quantity, mix, price and location of development could be estimated.

Transportation Infrastructure, Pricing, and Policies

The effect of transportation strategies can be assessed indirectly, through their representation in the travel models, and the consequent effect on the land use model system. Effects of a new highway, for example, on urban form, sprawl, housing and commercial development, and land prices could be estimated.

Hard Development Costs (replacement costs)

Although hard development costs are not explicitly a policy, some environmental or other regulations could potentially influence these costs. Effects of such policies could be estimated.

Soft Development Costs

Soft costs of development, such as development impact fees and service extension fees, or development subsidies that actually reduce such costs, can be represented directly in a scenario. Note that these, like the other policies identified above, can be very locationally-specific. For example, a tax abatement district, or a service extension area could be treated differently in terms of the costs of development.

Aggregate Metropolitan Growth

In addition, though not an instrument of growth management per se, the aggregate levels of economic activity within the region, specified as population and employment, are used as exogenous constraints, and can be used to test sensitivity under alternative growth scenarios.

Conclusions

We have outlined the motivation for a new analytical approach to simulating the effects of metropolitan growth management strategies, and provided a description of the most salient aspects of the design and specification of the UrbanSim model to address these requirements. The model has now been applied as a prototype case study in the Eugene-Springfield, Oregon metropolitan area, and is being tested in Honolulu and Salt Lake City. There are numerous limitations within the existing design, some of which are currently being addressed, and others of which will require substantial further development of both theoretical and empirical research. Our aim is to use this work as a foundation to stimulate the collaborative development of more effective analytical tools for growth management[5].

The current application of the model to Eugene-Springfield, Oregon has culminated in the calibration of the cross-sectional components of the model. The next stage in the development and testing of this model is a longitudinal calibration of the model dynamic behavior using historical data from Eugene-Springfield from 1980 to 1994. This will provide valuable feedback on the structure of the model in a dynamic formulation.

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[5] To facilitate collaboration, the software and model have been released as free software under the GNU General Public License For more information about the current status of the project and for access to extended documentation and source code, refer to http://urbansim.org.

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