

**An Urban Simulation Model for Integrated Policy Analysis and Planning:  
Residential Location and Housing Market Components of UrbanSim**

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Paul Waddell  
Associate Professor  
Graduate School of Public Affairs and  
Department of Urban Design and Planning  
University of Washington  
Seattle, Washington 98195  
pwaddell@u.washington.edu

## 1 POLICY AND PLANNING CONTEXT

Over the past several years we have observed increased public interest in mitigating the consequences of urban sprawl and making more systematic metropolitan plans that encompass land use, transportation and environmental dimensions. The connections between these domains are now readily apparent to the casual observer, and the public increasingly expects policies and plans in these arenas to be made consistent in shaping a sustainable path of urban development. Unfortunately, the analytical tools available to planners and policymakers have lagged far behind the public will to develop coherent metropolitan plans and policies, leaving decision makers inadequately prepared to anticipate the potential consequences of alternative policy initiatives or infrastructure choices.

In fact, the policy creation process at times leads to rather contradictory, or at least poorly integrated policy objectives. More often than not, the market effects and constraints of policy initiatives are given insufficient attention or are misunderstood. Overarching these concerns is the increasing fragmentation and polarization of public opinion about the basic goals of urban public policy over issues such as environmental preservation, economic development, quality of life, and social equity. Increasing public scrutiny of the political and technical decision making processes for land use, transportation, and environment adds further pressure on the policymakers to develop open, understandable, systematic, and objective approaches to devising and choosing between major policy strategies.

It is in this politically charged environment that we turn our attention to the evolving role of urban land use and transportation models. While land use models, in particular, received substantial criticism in the 1960's for their overly ambitious claims and poor performance by Lee (1973) and others, transportation models have become a standard part of the regional transportation planning process over the past three decades, as documented by Weiner (1997). In 1989, the role of land use and transportation models in the regional planning process was abruptly, and permanently, changed. The Sierra Club Legal Defense Fund and the Citizens for a Better Environment filed a lawsuit in Federal District Court of Northern California, claiming that the State of California, the Metropolitan Transportation Commission of San Francisco, and other agencies had violated the Clean Air Act Amendments of 1977 by not adequately addressing clean air standards (Garrett and Wachs, 1996). The focus of the case was on the failure of the planning process to account for the effects of increasing highway capacity on increasing air pollution emissions by reducing transit use, discouraging infill and densification, increasing highway speeds, inducing highway travel, and encouraging urban sprawl (Harvey and Deakin, 1991).

In the wake of this lawsuit and the subsequent Clean Air Act Amendments of 1991 and Intermodal Surface Transportation Efficiency Act of 1990, states and metropolitan planning organizations have been given a clear and urgent mandates to integrate land use, transportation, and environmental planning, and to incorporate maximum public participation in their decision making processes. The role of models as an objective and systematic core of the analytical basis for this activity is no longer in question. The question has shifted to how to improve and integrate land use, transportation, and environmental models, and how to integrate the technical modeling process with an essential public participation process. With the continuing threat of legal challenge hovering, the remaining question for most planning agencies is when this can be done.

It is within this context that the UrbanSim model has been developed. UrbanSim is a land use model developed for the Oregon Department of Transportation. It is a prototype metropolitan land use model for use by metropolitan planning organizations (MPOs) within the state. Its development was shaped by several constraints emerging from the context described above. First, it needed to integrate with existing travel models in use by MPOs in order to be implemented in the short term. Second, it needed to provide a direct capacity to analyze the impact of a range of growth management initiatives ranging from urban growth boundaries to comprehensive land use plans promoting nodal development patterns and mixed land use. Third, it needed to be developed in a way that would make it adaptable to other metropolitan areas of varying size and complexity, and to future integration with activity-based travel models now under development. And finally, it needed to be developed and tested within one metropolitan area, using mostly existing data. Eugene-Springfield was chosen as the site for the initial calibration and testing of the model.

Given this background, the development of the model was framed by theoretical, empirical, and practical constraints and requirements. It needed to be theoretically sound and behaviorally transparent for the purpose of communicating with policymakers and the public. It needed to integrate with existing travel models, rather than build a unified land use and travel model. It required an endogenous land market component to satisfy theoretical and policy analytic requirements such as the effects of urban growth boundaries on housing prices and densities. And finally, it needed to explicitly incorporate public policies embodied in land use and transportation plans, including factors such as environmental constraints on development.

The organization of the balance of the paper is as follows. Section 2 places the model within the context of existing research in land use modeling. Section 3 provides an overview of the key components of the model system. Section 4 describes the specification and estimation results for Eugene-Springfield, Oregon, and Section 5 concludes the paper with final observations and recommendations for further work.

## **2 LAND USE MODELING CONTEXT**

Reviews of the literature in urban land use modeling are in ample supply, with contributions by Anas (1987), Harris (1985), Kain (1987), Paulley and Webster (1991), Southworth (1995), and Wegener (1994, 1995), among others. This paper does not, therefore, attempt a systematic review of the literature, but presents the UrbanSim model within a context of existing work in land use modeling.

As pointed out by Anas (1982), the concept of 'bid rent' forms the basis of modern urban economic analysis and provides the foundation for most microeconomic models of urban spatial structure. The concept originated from von Thünen's (1826) work on agricultural land use, and became the centerpiece of Alonso's (1964) models of residential location and urban housing markets. This bidding approach, in the microeconomic tradition, assumes perfectly informed and efficient consumers make bids on all properties. Property owners, also fully informed, auction the property to the highest bidder, with steady state long-run equilibrium reached when this bid-auctioning process succeeds in allocating each property to the highest bidder. All consumers are expected to costlessly and instantaneously change residence when any change in conditions occurs that temporarily disrupts equilibrium, by repeating this bid-auction process. The monocentric model and its extensions by Alonso

(1964), Mills (1967) and Muth (1969) adopted the constraint that all employment was located in the central business district, and focused on the problem of predicting residential location as a function of transportation and housing costs.

Substantial research activity evolved in the direction of predicting housing prices, and the willingness to pay of consumers for the underlying attributes of housing. This body of work, which draws on Lancaster's (1966) theory of consumer behavior, views housing as a bundle of services, and households as utility maximizing consumers based on some function of these underlying attributes of housing, including locational characteristics. Rosen (1974) developed the hedonic theory of housing markets, in which households choose housing so as to maximize a utility function subject to a budget constraint. Extensions of this body of theory and empirical estimation of hedonic price functions have been widely published, beginning with contributions by Straszheim (1974), Wheaton (1977) and Galster (1977).

A separate stream of research activity emerged in parallel, focusing not on prices but on household residential choice. In particular, the work of McFadden (1973, 1978, 1984), Quigley (1973, 1976) and others on the use of random utility theory to develop multinomial logit models of residential location opened a significant direction for research in this area. This approach was used by Lerman (1977) to assess the importance of accessibility and mode on residential location, and by Williams (1977) to examine the effects of neighborhood on location choice.

Some research has emerged that crosses these two streams, notably work by Ellickson (1981) that develops a logit model of the property auction process using 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  $i$ :

$$P_{i|h} = \frac{e^{m(\Theta_{hi} - P_i)}}{\sum_j e^{m(\Theta_{hj} - P_j)}} \quad (1)$$

where:

$\Theta_{hi}$  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:

$$CS_{hi} = \Theta_{hi} - p_i \quad (2)$$

Martinez (1992) 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 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 (1985) also developed two stage models of the decision to move and the choice of location.

### 3 URBANSIM OVERVIEW

The UrbanSim model is based on the view of urban development 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 this model includes components modeling the behavior of these decision making units interfaced through the land market. As Wegener (1995) has pointed out, different urban processes take place on different time scales, with household and business location occurring over time periods of one year or less, construction of buildings occurring over slightly longer periods, and infrastructure planning and construction over much longer time frames. This model attempts to reflect this insight in its design by modeling urban development in a series of one-year steps.

The flowchart in Figure 1 presents a graphical view of the key components of the model system, each of which is described briefly in this section, followed by a more detailed treatment of the mobility and location choice model components that lie at the core of the model system. The model components represent the behavior of households, businesses, developers, and governments, all interfaced through the land market.

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 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 in the GIS viewer component of the user interface.

Two modules, demographic and economic transition, predict changes in the distribution of households and business by type (e.g. age, income, businesses by industry) at the regional level, consistent with exogenous aggregate forecasts of population and employment. 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.

In the household mobility and location module, 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. 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.

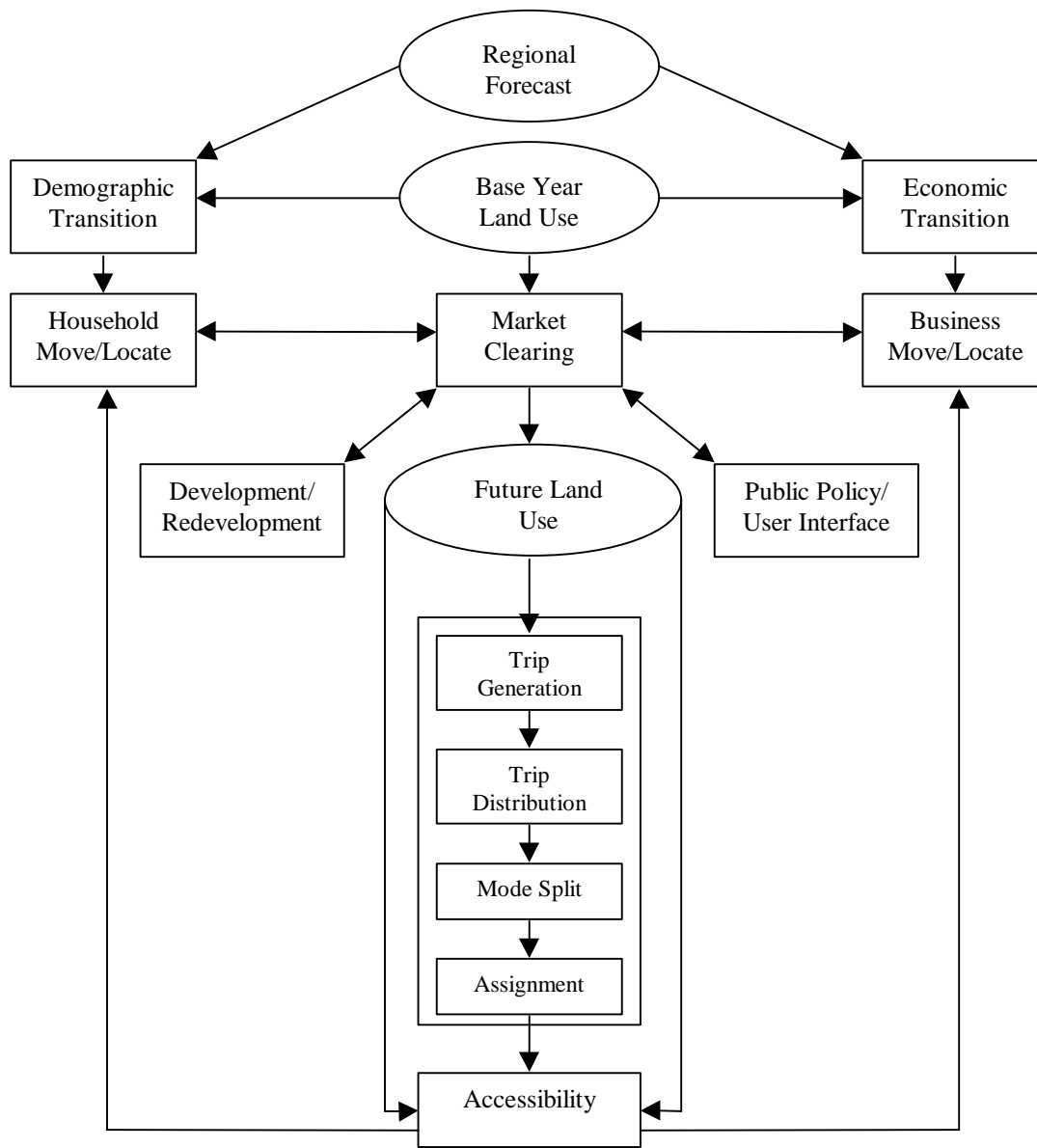
In the land development component, the model simulates developer choices to convert vacant or developed land to urban uses, including the type of improvements and density, based on their profitability expectations and subject to constraints imposed by governmental policies such as zoning and infrastructure 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 proportional 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.

In the following sections, a more detailed description of the residential and business location components of the model and estimation results for Eugene-Springfield are provided. There is, however, insufficient space for a full elaboration of each of the model components and the results of their estimation in this paper. For a more complete description of the balance of the model, see Waddell (1998a,b,c).

### **Figure 1: UrbanSim Model Structure**



### 3.1 Mobility and Location Choice

The location model we propose relates in key respects to the bid component of the model developed by Martinez (1992), based on consumer surplus (equation 1). It diverges from that model in significant ways, but most notably by dropping the equilibrium assumption. We assume that market prices are exogenous to the location choice faced by the individual consumer, and instead resolve price adjustments through an aggregate market clearing process external to the choices made by individual consumers. We structure time in annual steps, within each of which we account for mobility and location choices, as well as space construction decisions. Between years we account for price adjustment and new construction and redevelopment. Rather than imposing the equilibrium assumption that households make costless and instantaneous adjustments in residential location, we follow in the tradition of research that identifies a two-stage process of residential location, consisting of the decision to move, and the choice of location and dwelling type.

### **3.1.1 Aggregation of Alternatives**

Since we are not dealing with elemental housing units or lots as the level of choice, but are instead aggregating alternatives into zones (traffic analysis zones) and land use types, we need to adjust the choice equation to account for the aggregate nature of the choice set. We do this by including the size of the choice set represented by each of the aggregate choices. We rewrite equation 1 to include the size term, and substitute equation 2 into 1:

$$P_{i/h} = \frac{e^{m(CS_{hi} + \ln S_i)}}{\sum_j e^{m(CS_{hj} + \ln S_j)}} \quad (3)$$

This is the form of the location choice model we estimate.

Note that the model has a simple specification and direct interpretation. The consumer surplus is the difference, in dollars, between what a consumer is willing to bid for an alternative and the market price of the alternative. The log of the size term accounts for the aggregation of the elemental alternatives into zones of arbitrary size.

### **3.1.2 The Bid Function**

While the urban economic literature generally refers to a willingness to pay function that defines a hypothetical maximum a consumer would be willing to pay for an alternative, we suggest that the use of empirical data to estimate this function will reveal a function more aptly described as a bid function. What we actually observe when examining market outcomes of consumer choices is the prices they paid for the alternatives they chose. They might have been willing to pay more than they were required to by the market price for the alternative, but they would undoubtedly be reluctant to reveal their true maximum willingness to pay for it. What we observe, then, in examining actual market outcomes are the successful bids made by particular consumers, that match the market price for the alternative. This is consistent with the interpretation of consumers as price takers in the market.

This interpretation is summarized for the chosen alternative as the bid matching the market price and bounded by the maximum willingness to pay.

$$B_{hi} = P_i \leq \Theta_{hi} \quad (4)$$

In order to compare alternatives for predicting the probability that a consumer will select a particular one, however, we need to estimate a bid function that encapsulates consumer preferences for the attributes of the alternatives. The bid function must predict what consumers would have been willing to bid for each of the alternatives in the choice set based on their attributes.

The bid function we propose differs from the typical hedonic regression in that we stratify consumers into market segments, estimating a separate bid function for each. This allows the identification of bid price functions specific to subgroups of consumers, whose tastes vary significantly across incomes and stages of life cycle. A hedonic regression cannot be

interpreted as a demand function, since it represents the envelope of demand and supply curves of all consumers and suppliers in the market.

We estimate bid functions for households stratified by income level and by the presence of children, a key life cycle characteristic. For businesses, we estimate separate bid functions for each sector. Once the bid functions have been estimated, the bid 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.

### 3.2 Accessibility: The Land Use-Transportation Link

Before developing the specification of the model in further detail, we address briefly the linkage of land use and transportation through accessibility, in order to bring this into the model specification discussion that follows. 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 must deal with access 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 would 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 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:

$$Access_i = \sum_j^J A_j e^{\beta L_{ij}} \quad (4)$$

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  $j$ .

$\beta$  is the utility scaling parameter, initially set to 1

### 3.3 Market Clearing

Given the relaxation of the equilibrium assumption, we treat the adjustment of housing market prices as an aggregate market clearing process, exogenous to the location choices and bid formations of individual consumers. Households of different incomes and other characteristics are allowed to compete for housing, and allocated to available housing opportunities according to their consumer surplus. The imposition of market availability constrains the choices such that any given consumer may not realize their most preferred choice, in which case they are allocated to their highest available preference, at lower consumer surplus. This process continues, in a closed market, until all new and moving

households are assigned to their best available alternative<sup>1</sup>. We use the information on the original preferences, however, to determine the latent demand for each alternative, and incorporate this into the price adjustment process.

Since market clearing and price adjustment occurs at the end of each year, the adjusted prices will influence consumer surplus calculations and therefore locational preferences in the subsequent year. The response of developers to market signals also translates into new construction and redevelopment that becomes available in the subsequent year. These factors approximate the time lags and imperfect information that characterizes the operation of actual housing markets.

A full equilibrium price adjustment assumes perfect information and zero transaction costs, allowing prices on all buildings at each location to instantaneously adjust to the equilibrium solution that clears the market. Alternatively, our approach is based on an expectation of incomplete information and nontrivial transactions and search costs, so that movers obtain the best location available within a single year, and prices respond at the end of the year to the aggregate 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 (existing occupants plus the demand vector from the location choice model) for each housing type and location to the existing supply of housing of the appropriate type and location.

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, expressed as the ratio of demand to supply, 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, based on the density of the construction.
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.

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<sup>1</sup> At present there is no accommodation in the design for a homelessness outcome, although this refinement would be feasible.

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.

The form of the price adjustment, then, is:

$$P_{lbt} = P_{lbt-1} \left[ \frac{D_{lbt}}{(1-\alpha)S_{lbt}} \right]^{\beta}$$

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 type and location

$D_{lbt}$  is the total demand in the current year for space in the building type and location

$S_{lbt}$  is the current year total supply of space of building type b in location l

$\alpha$  is the normal vacancy rate

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

Total demand is estimated from latent demand and currently occupied space, discounted for vacancy to be created by out-movers:

$$D_{lbt} = \sum_i P(lb)_i M_{it} R_{lb} + \sum_i T_{ilbt} - (AV_{lbt} + TV_{lbt})$$

where:

$P(lb)_i$  is the prob. that a mover of type i will choose building type b, location l, year t

$M_{it}$  is the total number of movers of type i in year t

$R_{lb}$  is the utilization rate for building type b (for residential=1, for nonres.=sqft/emp)

$T_{ilbt}$  is the total quantity of space in building type b, location l in year t

$AV_{lbt}$  is the actual vacancy from previous year in building type b, location l, year t

$TV_{lbt}$  is the vacancy created by out-movers from building type b, location l, year t

#### 4 THE DATA

The area for this study encompasses the transportation planning area of the Lane Council of Governments (LCOG) in Oregon. The planning area lies towards the southern end of the Willamette Valley, on the Interstate 5 corridor. Like other metropolitan areas in Oregon, Eugene-Springfield is experiencing rapid growth, and attempting to manage this growth effectively within the constraints of state and local policy initiatives such as the Urban Growth Boundary. The planning area consists of 271 traffic analysis zones, which form the locational choices for the model.

Households are classified using five characteristics: household income, age of household head, household size, presence of children, and mobility, using the following categories:

Table 1: Household Classification Categories

Income	Age of Head	Household Size	Children	Mobility
Under \$10,000	Under 29	1	0	< = 5 years
\$10,000-24,999	20-49	2	1 or more	> 5 years
\$25,000-49,999	50-64	3		
\$50,000 or more	65 or Over	4 or more		

The data produce 111 unique non-zero household types from the cross-classification of these categories. For estimation of the probability that a household moved within past 5 years, all household types were used. For estimation of location choice, income and presence of children were used to stratify households.

The development of the 1994 base year household data at the zone level was developed using a ‘synthetic baseline population’ method developed by Beckman *et al* (1995) as part of the TRANSIMS project. This approach uses Iterative Proportional Fitting to generate a joint distribution of household characteristics with the required geographic detail, by linking the U.S. Census Public Use Microdata Sample (5%) with marginal distributions of household characteristics at the census block group level from Summary Tape File 3A. Iterative Proportional Fitting is applied to the household weights in the PUMS sample to estimate the joint distributions at a census block group level that are consistent with the geographically-detailed marginal distributions and with the aggregate joint distribution from the 5% PUMS household sample.

These joint distributions are converted from census block group to the zones used in the model using parcel data. Since the census block group and traffic zone can both be identified for every ownership parcel, the parcels with housing were used to develop an allocation from block group to traffic zone. The allocation procedure assumes that the households in a sample within a block group have a probability of location within a traffic zone that is proportional to the quantity of housing of the type occupied by the household. This process is implemented using a sampling procedure that also scales the household weights from 1990 to the model base year of 1994, assuming that the distribution of household types remained consistent over that time.

The housing inventory and prices originate from the Lane County parcel database. Assessed values are used as surrogates for market prices in the base year, since sales data would be insufficient to populate values for each zone and housing type. In Oregon, properties are assessed at full market value, though errors in the assessed values clearly add noise to the estimation of the bid functions. The advantage of this procedure is that it uses available data sources so it can be readily replicated. It also provides a large sample size for estimation of the residential mobility rates and location and housing type choice components of the model. The alternative of using household travel surveys to estimate the location choice model would be preferred in metropolitan areas having surveys with sufficient sample size. Similarly, an alternative to assessed values would be preferred for the market price estimates, but the results discussed in the following section suggest that in spite of the inevitable data measurement errors from the data described here, the results of estimation appear reasonable and robust.

## 5 MODEL SPECIFICATION AND ESTIMATION RESULTS

The prototype model has now been specified and calibrated for Eugene-Springfield, Oregon. In the interest of space, we focus our presentation of results of this work on the residential location choice component of the model. We review below the specification of the bid functions, and results from the estimation for households.

### 5.1 Household Bid Function

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.

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 and Mullen, 1984), 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 a higher income mix.

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.

Finally, we test for market supply effects on bids by including the size of the housing stock in the neighborhood. 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 lower the market price, and therefore the bid. 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 to underlying consumer preferences, and leaves the market price adjustment external to the formation of bids. The variable definitions are presented in Table 2, and results of estimation of the bid price functions of households stratified by market segments by income level and age of children in Table 3.

These results provide strong support for the core hypotheses described in this section. Taken together, the model explains approximately three-fourths of the variation in the bid prices of these household market segments. In addition, the segmentation of the market by income and presence of children is borne out by informal comparison of coefficients across market segments, and is substantiated by more rigorous Chow tests.

In almost all cases, the results had the expected signs and were significant at the five-percent level. Compared to single-family housing, we find consistent discounting of bids for duplex/quadplex and multifamily housing. Density, the inverse of lot size, is consistently

negative and significant in all but two cases. Access to employment is consistently significant and positive, as is access to shopping<sup>2</sup>. Age depreciation was reflected in lower bids, with a trend that higher income households discounted for age more heavily than lower income households. A consistent pattern also emerged from the income composition of the neighborhood, with all household types discounting for higher percentages of the two lowest income levels, and increasing bids for neighborhoods with greater concentration in the highest income level. This pattern of coefficients supports the housing filtering hypothesis, and the underlying conversion of upward social mobility into residential location choices in more affluent neighborhoods. The wealthiest households will tend to outbid for the newest housing with the highest concentration of wealth, and lower income households will move up through the vacancy chain as affluent households move into new housing.

Table 2: Household Bid Price Variables

	Definitions
Residential 2-4	Dummy variable for housing type residential with 2-4 units (duplex, triplex or quadplex)
Multi-family	Dummy variable for housing type multi-family, with 5 or more units
lnAccEmployment	Log of accessibility to total employment, with an exponent on the logsum of 1
lnAcc4Retail	Log of accessibility to retail employment, with an exponent on the logsum of 4
Density (units/acre)	The net density in units per acre of a particular housing type in a zone
lnUnits	Log of the number of housing units of a particular type in the zone
lnAge	Log of the average age of the buildings of a type in a zone
PctIncome1	Percent of households in a zone in the lowest income group
PctIncome2	Percent of households in a zone in the second lowest income group
PctIncome4	Percent of households in a zone in the highest income group
PctChild	Percent of the households in a zone that have one or more children
PctLandIndustrial	Percent of the developed land in the zone that is in industrial use
PctLandResidential	Percent of the developed land in a zone that is in residential use
TimeToCBD	Travel time to the Central Business District, in minutes

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<sup>2</sup> Access to shopping was measured with a value of four on the exponent of the logsum composite utility of travel, compared to an exponent of one for employment access. This reflects more localized accessibility to shopping opportunities.

Table 3: Household Bid Price Functions

	INCOME GROUP 1		INCOME GROUP 2		INCOME GROUP 3		INCOME GROUP 4	
	Child	No Child	Child	No Child	Child	No Child	Child	No Child
Intercept	0.8661 (0.759)	5.0712 (5.170)	0.8730 (0.680)	3.3327 (3.227)	4.9405 (7.243)	5.5321 (8.915)	7.2061 (3.197)	4.1270 (1.163)
Residential 2-4	-0.4297 (-15.306)	-0.4815 (-19.994)	-0.4507 (-15.398)	-0.5162 (-22.857)	-0.4179 (-9.869)	-0.5848 (-30.252)		-0.7776 (-6.979)
Multi-family	-1.0447 (-27.161)	-1.0189 (-41.734)	-1.1022 (-20.692)	-1.0711 (-33.888)	-1.1099 (-9.894)	-1.3607 (-35.988)	-0.9856 (-4.170)	-1.8252 (-20.402)
lnAccEmployment	0.8089 (8.081)	0.4326 (5.045)	0.7912 (6.845)	0.6155 (6.694)	0.4593 (7.167)	0.4198 (7.059)	0.3329 (1.619)	0.6557 (2.020)
lnAcc4Retail		0.0307 (3.427)	0.0077 (0.931)	0.0075 (0.954)	0.0347 (3.983)	0.0087 (0.999)	0.0955 (5.799)	0.0403 (1.537)
Density (units/acre)	-0.0063 (-5.488)	-0.0053 (-9.786)	-0.0091 (-4.530)	-0.0061 (-6.963)	-0.0310 (-7.605)	-0.0018 (-1.557)	-0.0128 (-2.700)	-0.0020 (-0.592)
lnUnits	-0.0016 (-0.131)	-0.0270 (-2.850)	-0.0056 (-0.532)	-0.0271 (-3.104)	-0.0011 (-0.094)		-0.1389 (-6.510)	-0.0351 (-1.202)
lnAge	-0.0929 (-3.775)	-0.0789 (-4.484)	-0.0791 (-3.229)	-0.1416 (-7.672)	-0.1789 (-7.008)	-0.1770 (-8.486)	-0.3714 (-9.261)	-0.5391 (-9.385)
PctIncome1	-0.0131 (-12.603)	-0.0096 (-10.906)	-0.0142 (-15.290)	-0.0102 (-11.828)	-0.0123 (-12.604)	-0.0107 (-11.475)	-0.0103 (-4.937)	-0.0064 (-1.893)
PctIncome2	-0.0145 (-12.006)	-0.0161 (-14.971)	-0.0157 (-14.684)	-0.0140 (-14.921)	-0.0166 (-14.184)	-0.0137 (-13.167)	-0.0178 (-10.116)	-0.0084 (-3.419)
PctIncome4	0.0045 (1.642)	0.0098 (4.505)	0.0075 (3.600)	0.0157 (8.996)	0.0030 (1.738)	0.0080 (4.924)	0.0019 (0.861)	0.0094 (2.803)
PctChild	0.0032 (3.445)	0.0026 (3.211)	0.0059 (7.029)	0.0027 (3.376)	0.0014 (1.501)	-0.0020 (-2.050)	-0.0061 (-3.863)	-0.0144 (-5.798)
PctLandIndustrial	-0.0057 (-6.241)	-0.0108 (-15.680)	-0.0051 (-6.077)	-0.0097 (-14.347)	-0.0029 (-2.852)	-0.0057 (-5.292)		-0.0188 (-4.819)
PctLandResidential	0.0011 (1.732)		0.0027 (4.944)		0.0053 (9.612)	0.0031 (5.870)	0.0099 (12.323)	0.0039 (2.971)
TimeToCBD	0.0204 (2.642)	0.0126 (2.006)	0.0187 (2.552)	0.0129 (2.033)			0.0160 (1.377)	0.0181 (0.964)
N	1352	2432	1681	2878	1413	2085	438	508
Adjusted R <sup>2</sup>	0.76	0.79	0.73	0.73	0.69	0.74	0.76	0.73

After accounting for the access to employment and shopping, proximity to the central business district is discounted in bids for most household types. This discounting perhaps reflects negative externalities associated with proximity to the center, such as localized congestion, noise, school quality, or crime, or other factors not included in the model.

The relative preference of households with children for neighborhoods with higher proportions of households that have children appears to be generally supported, but with an interesting trend across income levels. Lower income households tend to bid higher for neighborhoods with higher proportions of children, while the highest income households tend to discount their bids somewhat at higher concentration of households with children.

The relative bids for this attribute within each income level suggest consistency in households with children bidding higher than those without children, but the income trend remains. One potential explanation for this trend is that neighborhoods with a high proportion of households with children are a fairly middle-class phenomenon, which represents an attraction for lower income households, and a deterrent for the highest income households.

The land use mix in a neighborhood was found to be significant and reasonably consistent, with a higher percentage of the developed land in a zone in residential use prompting higher bids, and more industrial land associated with discounting. The preference for residential land, and its associated characteristics, increased with income. The distaste for industrial land appeared to be more significant for households with children than those without.

There were some exceptions to the consistency of the results. The market supply effect, measured by the log of housing units, was negative in all but one case, but varied in significance across household groups. This variable was dropped from the one case in which it was positive. Similarly, exceptional signs were found on residential land for childless low and low-middle income households, which might reflect their preference for multi-family housing, but for policy analytical purposes a negative coefficient on residential land is problematic, and was dropped. Travel time to the CBD was dropped for income group three, in which it was insignificant, and for childless households, negative.

## **5.2 Logit Estimation of Residential Location Choice and Housing Type**

The fitted bid functions described in the preceding section were used to generate estimates of the consumer surplus of each alternative, and were included in a much simpler logit specification that included only the consumer surplus estimate and the log of the size variable.

Since the estimation of consumer surplus for all households makes them directly comparable, and we expect that households of all types compete in the housing market according to their consumer surplus, we pool all households for the logit estimation of location choice. The results are shown below.

Table 4: Logit Estimation Results for Residential Consumer Surplus

Variable	Coefficient	Z (b/s.e)
Consumer Surplus	4.73E-05	6.748
LnSize	2.30E-02	4.156

Log-Likelihood estimated: -70047  
Log-likelihood with no coefficients: -81592

These results provide confirmation of the basic structure of the model, with expected signs and significance on the two terms. The greater the consumer preference, the more likely a consumer is to choose the option. The larger the number of underlying alternatives within an aggregate choice (zone), the more likely a consumer is to choose it, holding constant the consumer surplus of the alternatives.

## 6 CONCLUSIONS AND RECOMMENDATIONS

We have presented only the residential and business location components of the UrbanSim model here due to space limitations. The full model system has been calibrated and implemented in software. Other papers will follow that describe the remaining components of the model in detail and their implementation results. The partial results reported here provide a valuable test of the work done to date, and a foundation for the further development of this modeling strategy. A historical validation exercise is now underway to learn more about the ability of the full model system to capture key influences on location choices and prices over a 10-15 year period of history.

Future directions for development of the model include its application in other metropolitan areas of varying sizes and conditions, and a series of specific extensions of the model and its software implementation. One priority for future research is increasing the resolution of location choices using a grid representation of land that allows better measurement of localized spatial context. This development will be important to improving the model's sensitivity to urban design scale characteristics that may influence non-motorized and transit mode share and residential location choices.

A second priority for development is a microsimulation implementation of the location choice and market clearing components of the model (the land development component is already based on microsimulation at the parcel level). While the current model does not attempt to link the residence and workplace of the individual workers within the household, it may be worthwhile, or necessary, to attempt this complication within a microsimulation implementation. A microsimulation model with linkages between job and residence changes, especially in households with multiple workers, presents a significant challenge for specification and calibration. The microsimulation approach and grid representation of location set the stage for the development of more direct linkages to environmental models to better integrate the analysis of urban development with the assessment of the environmental impacts of development alternatives. Waddell and Alberti (1998) have developed a general framework for linking this model to a human stressor model to integrate urban and ecosystem modeling and strategic analysis.

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