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Incorporating land use in metropolitan transportation planning

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Abstract

In current practice, very few Metropolitan Planning Agencies attempt to capture the effects of transportation system changes on land use, and the consequent feedback effects on transportation system performance, despite substantial evidence that these effects may be significant. In this paper, we present a case study on the application of UrbanSim, a detailed land use simulation model system, and its integration with a regional travel demand model in the Greater Wasatch Front area of Utah. Like several other metropolitan areas, this region has recently been confronted with legal challenges to proposed highway projects, drawing substantial scrutiny to the land use-transportation connection. We describe the UrbanSim model specification, results from model estimation, and sensitivity analyses conducted with the combined land use and travel model system. The results of the sensitivity analysis suggest that accounting for the land use effects of a regional transportation plan may produce significant shifts in key transportation evaluation measures such as vehicle miles traveled, vehicle hours traveled, and hours of congestion delay.

Keywords: Land use model; Land use – transport interaction; Urban simulation

1. Introduction

The impact of transportation improvements on urban development is perhaps one of the most important, and contested, concerns in metropolitan transportation planning today. On the one hand, it has long been known that transportation accessibility fundamentally influences firm location, household location, real estate development, land prices, and density (von Thünen, 1826; Muth, 1969; Mills, 1967; Alonso, 1964). The

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practice of transportation planning, however, has until recently routinely ignored the effects of major transportation improvements on urban form, and the consequent indirect effects that such induced development can have on the efficacy of alternative transportation investment strategies. Regional Transportation Plans prepared by Metropolitan Planning Organizations very rarely acknowledge any feedback effects from transportation improvements on land use, and thereby ignore these effects on project and plan evaluation. This omission has the potential consequence of exaggerating mobility and environmental benefits of transportation projects, and undervaluing the potential benefits of land use or integrated land use and transportation policies.

The importance of this feedback of transportation on land use has been recognized in federal policy since the passage of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991, and has prompted legal challenges by environmental advocates in numerous metropolitan areas on the grounds that air quality conformity results may be overly optimistic where these feedback effects are ignored. Although some research has argued that the relative effects of accessibility are becoming less important in determining outcomes such as residential location as compared to other factors such as amenities (c.f. Giuliano, 2004), the fact remains that there is a very high degree of mutual influence between the evolving urban form of a metropolitan area and its transportation system. Why, then, is this effect so widely ignored in contemporary metropolitan transportation planning?

One explanation that has been put forward is an institutional and political one: the predisposition of transportation planning institutions towards road construction, whereby there is an incentive to ignore feedback effects such as long-term induced demand that might reduce the perceived value of desired projects. Given that much of the funding for road improvements is from federal sources, there is a potential incentive to export the costs of these projects and not fully account for these costs when evaluating projects. Whether or not this hypothesis is valid, it does not provide a compelling rationale to ignore the effects of transportation on land use. A second explanation that has some credibility is that there is insufficient theoretical understanding of the interconnections between transportation and land use, or alternatively that these connections are too complex and chaotic to account for in a formal analysis or model. This explanation may have some merit, but advances in theoretical and quantitative analysis on location choice, urban development, and real estate markets suggest that this rationale is insufficient to justify failing to account in some form for these feedbacks. Finally, the claim that there are no available models for widespread use by planning staff in Metropolitan Planning Agencies, or that the models are too complex or data hungry, is raised as a practical limitation. While there has been a long hiatus in the development of land use models for integrated land use and transportation planning, there has been a rapid resurgence in research and development of such models over the past five to ten years, though the assessment of these models remains sparse (Miller et al. 1999; Dowling et al., 2005). This paper addresses these barriers to incorporating transportation-land use interaction into contemporary metropolitan transportation planning, by describing a case study in the operationalization of an integrated land use and transportation model system, in the context of legal contention over a highway project.

The objective of this paper is to present the results of a project to evaluate the application of the recently developed UrbanSim land use model system and its integration with the Wasatch Front Regional Council (WFRC) four-step travel model system. We describe as thoroughly as available space permits the process of developing and applying UrbanSim in the Greater Wasatch Front Region, including the development of the database, estimation and calibration of model parameters, integration with the WFRC travel model system, and validation of the model system through sensitivity analyses designed to explore the responsiveness of the model to major transportation system and land use policy changes. A key finding of this research is that by incorporating the feedback of transportation on land use, predictions of the vehicle miles traveled (VMT) and vehicle hours traveled (VHT) increase by 5% compared to the 2030 Long Range Plan baseline (which did not consider this feedback), and the total hours of congestion delay (TCD) increased by almost 16%, confirming that this feedback is important to address in regional transportation planning.

The paper is organized as follows. In the Section 2, we describe the political and institutional context of the case study, which presents challenges that are at least as important as the technical ones. We then describe in Section 3 the project scope, including the evaluation framework for the project. In Section 4, we provide an overview of UrbanSim and its components, including representative results from the model development and estimation in this region. We then address the coupling of UrbanSim and the regional travel model system in Section 5, followed by a discussion of sensitivity analyses designed to test the integrated model system in

Section 6. The paper concludes with discussion of the evaluation of the Peer Review Panel in Section 7, subsequent actions taken by the WFRC to bring the integrated model system into operational use in Section 8, and concluding comments and directions for further research in Section 9.

2. Political and institutional context

The Greater Wasatch Front Area, containing 80% of Utah's population and centered on Salt Lake City, is a rapidly growing metropolitan area. The problems presented by Utah's rapid growth are compounded by several factors unique to the area, including the physical constraints imposed by the surrounding mountains and the Great Salt Lake, and by an abundance of critical environmental resources that require protection. These constraints limit the supply of developable land to accommodate a projected doubling of the region's population and employment over the next thirty years, precipitating an increasing sense of urgency about how to maintain the quality of life the region enjoys, including the quality of its natural environment.

By the year 2020, population and travel demand in the five counties along the eastern shore of the Great Salt Lake is predicted to increase by 60 and 69 percent, respectively. In order to deal with this projected demand, Utah state, regional, and local officials developed a series of transportation improvement plans collectively known as the "Shared Solution". The Shared Solution calls for widening Interstate 15, enhancing transportation systems and management, increasing the availability and usage of mass transit, and constructing the Legacy Parkway Project.

The Legacy Parkway is planned as a four-lane, limited-access, divided highway starting near Salt Lake City and extending north approximately 14 miles to US 89. The project includes a pedestrian/equestrian/bike trail and will block traffic noise by using earthen berms rather than sound walls. The 14-mile Legacy Parkway should not to be confused with the 100+-mile Legacy Highway – running from Brigham City to Nephi – proposed by Utah Governor Michael Leavitt in 1996. That project has been the subject of considerable controversy, leading to a series of legal challenges.

In order to begin construction, the Legacy Parkway Project required approval from the Federal Highway Administration (FHWA) because it would merge with the interstate highway system. The project also needed to obtain a 404(b) permit from the US Army Corps of Engineers (COE) because construction would entail the filling of 114 acres of wetlands. Both the FHWA approval and COE permit were considered major federal actions that required an Environmental Impact Statement (EIS). Between 1996 and January 2001 the Utah Department of Transportation (UDOT) prepared a draft and final EIS, awarded the contract for construction of the Legacy Parkway, obtained the COE 404(b) permit, and was granted approval by the FHWA.

In response to these approvals, on January 17, 2001, the Non-Governmental Organization (NGO) Utahns for Better Transportation (UBT) and Salt Lake City Mayor Rocky Anderson filed a suit in federal district court alleging that the FHWA and COE violated the National Environmental Policy Act (NEPA) and the Clean Water Act (CWA). The Sierra Club filed a second suit against the US Department of Transportation adding a Clean Air Act (CAA) complaint alleging that the Salt Lake area Transportation Implementation Plan was in violation of transportation conformity requirements and that Legacy Parkway would result in increased mobile source emissions. The UBT and Sierra Club cases were consolidated by the district court and the CAA conformity claims were separated from the Legacy Parkway permitting and review claims.

On August 11, 2001, US District Judge Bruce S. Jenkins dismissed the plaintiff's permitting and review claims, upholding the 404(b) permit decision and FHWA approval process, thereby ruling in UDOT's favor. The plaintiffs filed for injunctive relief with the federal district court and after being denied, filed for injunctive relief with the 10th Circuit Court of Appeals. On November 16, 2001, the 10th Circuit Court of Appeals granted injunctive relief, and construction on Legacy Parkway was halted. On September 16, 2002, the court ruled in favor of the plaintiffs, citing inadequacies of the EIS and the permitting process.

On June 26, 2002, the Sierra club, U.S. DOT, FHWA, Federal Transit Administration (FTA), COE, and the State of Utah entered into an agreement to settle the conformity claims against the Legacy Parkway. Under the terms of the settlement, one element stipulated that an assessment be conducted of the use of UrbanSim in conjunction with the regional travel model system operated by the WFRC. A favorable assessment of UrbanSim would obligate WFRC to begin using UrbanSim to produce socioeconomic and development forecasts and integrate these into WFRC's operational planning activities, such as updating the Long-Range Transportation

Plan (LRP), Transportation Improvement Program (TIP), and corridor planning projects. This assessment was financially supported by a grant from FHWA that had been made independently as a match to a National Science Foundation Digital Government grant awarded to the University of Washington.

In many ways, the controversy over this highway project reflects a broader trend across the nation, with many metropolitan regions facing similar problems, as highway projects have become embroiled in political and increasingly litigious battles. The origins of the controversies vary from place to place, but there are common elements, such as concerns over the long-term effects of major highway on urban development and additional travel. While not every aspect of this particular case is generalizable to others, it is likely that lessons learned in this case may have some bearing on other, similar cases. In the words of an anonymous reviewer, "It presents a potential landmark precedent for the requirement of alternative land use scenarios to be required in regional long range transportation planning."

3. Project scope

The assessment of the integration of UrbanSim with the regional travel model system was launched in 2003 with the formation of a Peer Review Panel and the organization of a Management and Policy Committee and a Scenarios Committee. The Management and Policy Committee represents stakeholders from WFRC management and other related organizations, and was established to address questions relating to the incorporation of UrbanSim into the policy and institutional setting in the region. The Scenarios Committee consists principally of planners from jurisdictions in the region, and was established to provide local input to and review of scenarios tested. The Peer Review Panel, consisting of technical experts in land use and transportation modeling, were charged with the overall coordination of the evaluation, and with making recommendations to the WFRC on the use of UrbanSim in operational planning. Due to the schedule stipulated in the terms of the settlement, the entire review had to be completed by the end of 2003.

The first meeting of the Peer Review Panel (PRP) was held June 26–27, 2003 to organize the work scope and obtain initial feedback from the PRP. The core of the recommendations of the PRP were to document the model system and its development and calibration, and to conduct a validation of the combined UrbanSim – Travel Model system using a series of tests, which we describe in detail in Section 6.

3.1. Framing the evaluation

The evaluation of UrbanSim (or any other model) as a tool for operational planning in conjunction with the regional travel models involves many considerations, broadly grouped into the validity of the model system and its usability. Some of the questions the evaluation of the UrbanSim model application were intended to consider are outlined below. We return to the summary assessment of these questions by the Peer Review Panel in the closing section.

3.1.1. Model validity

- Is the model structure theoretically sound? Based on a review of the written documentation of the model system and of the presentations, are there any theoretical deficiencies in the model design that would undermine the validity of the model and its capacity to address the intended planning functions within the region? Are there areas in which it could be improved?
- Are the quantitative methods used in the model appropriate? Are there any concerns about the validity of the quantitative methods used in the model system (multinomial logit, multiple regression, monte carlo simulation)?
- Are the estimation results valid? Based on review of the documentation of the model specification and estimation results for the Wasatch Front region, are there any significant concerns about the estimation results that would call into question the validity of the model?
- Are the simulation results reasonable? Given the absence of sufficient historical data with which to undertake a historical validation of the model in the Wasatch Front Region, the simulation results must be

evaluated against theory and local knowledge. Based on this review, are there any significant concerns about the validity of the simulation results?
- Is the model appropriately sensitive to constraints and policies of interest, especially effects of major transportation improvements? Do the model predictions show patterns of response to changes in key policy variables, such as the transportation system, that are consistent with theory and local knowledge? To which policies should the model be made sensitive in the regional planning context?
- Does it integrate well with the regional travel model system? Is the approach to integration with the travel model specified and implemented in a way that is consistent with theory?

3.1.2. Model usability

- Does the model have an effective user interface? What characteristics would be useful in the user interface to support the range of intended applications for the model?
- Is the computing performance adequate? What level of computing performance would define a usable system for interaction with the travel model system, given an expectation of running the travel model approximately every three to five years of simulated time?
- Are requirements for data and expertise manageable? What level of staff support and expertise is appropriate to devote to the land use model as a part of the broader integrated regional modeling system? Do UrbanSim's requirements fall within those limits?
- Does it produce needed indicators or performance measures for diagnosis and evaluation? Given the range of possible policies to be evaluated, which indicators would be useful to local stakeholders for effectively evaluating alternative policy scenarios?
- Does it integrate adequately into the institutional and political context? What are the institutional and political concerns regarding the use of UrbanSim in the region? How should the UrbanSim implementation be managed and accessed by various stakeholders in the roles of creating scenarios, running the model system, and evaluating results? How should local land use policies, major transportation alternatives, major development plans, regional visioning, and other significant inputs be incorporated?
- How useful is it in different use cases, including updating the regional transportation plan, corridor planning, regional visioning, and local community planning? What are the different usage contexts, or situations, envisioned for applying UrbanSim? In each of these use cases, who are the stakeholders and what criteria are important to them in evaluating the use of the model system?

3.2. Comparison to current procedures

In order to assess the potential for operational use of UrbanSim by the WFRC, it must be examined in comparison to the existing operational procedures for land use forecasting. The current land use forecasting procedure is based on a trend-based model to allocate households, population and jobs by five sectors to Traffic Analysis Zones. It is implemented in a spreadsheet, and has enhancements to account for capacity constraints and planned developments. The land use forecasting process relies on considerable review and adjustment based on an expert panel and by the cities in the region. It does not attempt to include any assessment of feedback of transportation improvements on land use.

4. Overview of UrbanSim

In this section of the paper we describe the theory and specification of the model system and its components as applied to the Greater Wasatch Front Region. UrbanSim is a simulation system that integrates several land use model components, and has been linked to a recently updated travel demand model system in Utah. Fig. 1 depicts the model components and their relationships. The UrbanSim model system and software architecture is described in detail elsewhere (Waddell, 2002; Waddell et al., 2003a; Noth et al., 2003), and is available as Open Source software at http://www.urbansim.org. Compared to existing operational land use models,

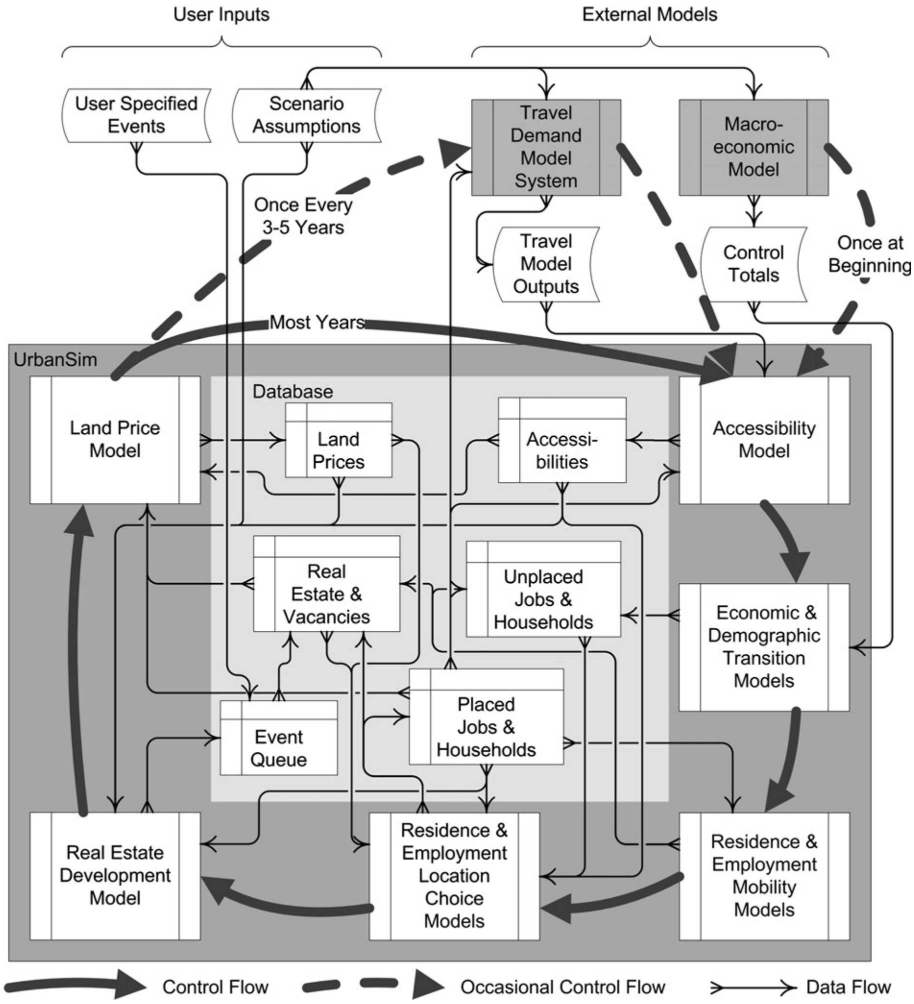

Fig. 1. UrbanSim model structure and data flow.

UrbanSim is unusual in several respects, but most notably its use of individual agents, the explicit representation of the demand and supply sides of the real estate market as well as prices, a dynamic representation of time (as compared to equilibrium models), and its design to be sensitive to a range of policies. A detailed comparison of UrbanSim to other models is beyond the scope of this paper, but thorough model comparisons are available in Miller et al. (1998, 1999) and Dowling et al. (2005).

4.1. Integrated model architecture

As a complete land use and transportation model system, UrbanSim includes five interacting models, and it links to two exogenous model systems: a macroeconomic model, to predict future macroeconomic conditions such as population and employment by sector; and a travel demand model system, to predict travel conditions such as congested travel times and composite utilities of travel between each interchange. Since the macroeconomic model does not depend on outputs from UrbanSim, the macroeconomic data can be forecast independently and used as fixed inputs to UrbanSim.

The main model components in UrbanSim, in the order of their execution, are the accessibility model, the economic and demographic transition models, the household and employment mobility (intra-urban relocation) models, the household and employment location choice models, the real estate development model, and the land price model. Each of the key model components are described in more detail in Sections 4.3 and 4.4. Data flows among model components are shown in Fig. 1.

The model system reads exogenous inputs not only from external macroeconomic and travel demand models, but also from user input. These user inputs include assumptions reflecting land use policies that regulate real estate development, and any user-specified events that describe scheduled events representing changes in employment, real estate development or land policy the user intends to apply to the model in a specific simulation year.

A key element of the model system is that real estate development is acknowledged to require a longer time frame than location choices made by firms and households. Developers must monitor market conditions and trends, acquire a site, acquire financing, obtain permits, prepare the site (often requiring infrastructure extensions), and undertake construction that might require several years in the case of large-scale projects. As a result, the interaction of demand and supply sides of the market can be characterized as an ongoing series of adjustments to varying degrees of market disequilibrium. Building booms and busts, and volatile swings in rents, prices and vacancy rates, are all well-known symptoms of the disequilibrium in real estate markets. This perspective leads to a model design that represents demand as operating in a short-term period (which we simplify to under one year), given a fixed supply of real estate within this time frame. Choices of developers, on the other hand, are modeled as a response to current and previous market conditions, and development projects are scheduled for implementation at least one year in the future to reflect the inherent time lags in the development process. The dynamic adjustment of demand, supply and prices used in the UrbanSim design, and the path dependence that it generates, contrasts with the more traditional static equilibrium modeling approach taken in other land use models that simulate real estate markets.

4.2. The database

The input data used to construct the model database include parcel files from tax assessor offices; business establishment files from the state unemployment insurance database or from commercial sources; census data; GIS overlays representing environmental, political, and planning boundaries; and a location grid. A set of software tools, collectively referred to as the data integration tools, reads these input files, diagnoses problems in them such as missing or miscoded data, and applies decision rules to synthesize missing or erroneous data and construct the model database.

Each household in the metropolitan area is represented in the database as an individual entity, with the primary characteristics relevant to modeling location and travel behavior: household size, number of workers, presence of children, age of head, and household income. The household list is synthesized by integrating census household-level data from the Public Use Microdata Sample with Summary Tape File 3A tabulations by census tract, and assigning synthesized households probabilistically to parcel data, using a variant of the procedure developed for the TRANSIMS model system (Beckman et al., 1996). Employment is represented in the database as individual records for each job and its employment sector.

Locations are represented using grid cells of 150 by 150 meters, which contain an area just over 5.5 acres (the cell size can be modified). This location grid allows explicit cross-referencing of other spatial features including planning and political boundaries such as city, county, traffic zones, urban growth boundaries; and environmental features such as wetlands, floodways, stream buffers, steep slopes, or other environmentally sensitive areas.

Parcel data are collapsed into the cells to generate composite representations of the mix and density of real estate at each location, which we refer to as development types. These development types are somewhat analogous to the development typology developed by Calthorpe (1993), in that they represent at a local neighborhood scale the land use mix and density of development. A database table stores the rules for classifying grid cell development into types, based on the combination of housing units, nonresidential square footage, and the principal land use of the development.

The database maintains an explicit accounting of real estate and occupants, linking individual households to individual housing units, and individual jobs to job spaces that can be either nonresidential square footage or a residential housing unit to account for home-based employment. When jobs or households are predicted to move, the space they occupy is reclassified as vacant, and when they are assigned to a particular housing unit or job space, that space is reclassified as occupied. By explicit assignment of housing units and nonresidential square footage to grid cells of fixed size, densities and mixtures of housing units and nonresidential square footage of industrial, commercial, or governmental types are inventoried. Land values and residential and nonresidential improvement values are also identified for each cell in the database. This integrated database of households, jobs, land, and real estate is what the model components update over time. Although this database is derived from data about real households, businesses, and parcels, it is a synthetic database that represents only selected characteristics of people, jobs, real estate, and locations. Similarly, the models and their estimated parameters attempt to reflect the patterns of observed behavior of real agents but are simplifications and abstractions of real behavior, as are all models.

4.3. Discrete choice-based model components

Exploiting the Random Utility Maximization (RUM) models pioneered by McFadden (1974, 1981), UrbanSim implements the residential location choice, employment location choice, and real estate development choice models as discrete choice models. We describe this common framework before discussing each model component individually. We assume that each alternative i has associated with it a utility U_i that can be separated into a systematic part and a random part:

$$U_i = u_i + \epsilon_i, \tag{1}$$

where $u_i = \boldsymbol{\beta} \times \mathbf{x}_i$ is a linear-in-parameters function, $\boldsymbol{\beta}$ is a vector of k estimable coefficients, $\mathbf{x}_i$ is a vector of observed, exogenous, independent alternative-specific variables that may be interacted with the characteristics of the agent making the choice (e.g. household characteristics in the residential location choice model), and ϵ_i is an unobserved random term. Assuming the unobserved term in (1) to be distributed with a Gumbel distribution (Type I extreme value distribution) leads to the familiar multinomial logit model (McFadden, 1974, 1981):

$$P_i = \frac{e^{u_i}}{\sum_j e^{u_j}}, \tag{2}$$

where j is an index over all possible alternatives. The estimable coefficients of (2), $\boldsymbol{\beta}$, are estimated with the method of maximum likelihood (see, for example, Greene, 2002).

We have used standard multinomial logit specifications throughout the model system, which have a closed form specification of the probabilities and are efficient computationally. More flexible choice model specifications are available, such as mixed logit, and may be suitable for the models at hand, but come with considerable computational expense, since they lack closed form probabilities. Given the need for computational efficiency in this project, we leave for future work the examination of alternative discrete choice model specifications. Similarly, one might contend that decision-makers are not always rational, or that they might use particular heuristics for searching or selecting among alternatives. While there may be merit to these concerns, we do not resolve them in the current project. In later work we have begun to generalize the choice modeling framework to allow testing of alternative choice model specifications and heuristics.

4.3.1. Employment location choice

We begin the description of UrbanSim models with a description of the employment location choice model, as employment location is a critical driver of urban form. Theoretical models of employment location date at least to the seminal work of von Thünen (1826), which described a negatively sloped agricultural land rent gradient as distance from a central market increases to offset increased transportation costs to the market. This early work on bid-rent later stimulated the development of the monocentric model of urban structure (Muth, 1969; Mills, 1967; Alonso, 1964). Early applications of spatial theory of urban firm location can be traced to Christaller's (1933) work on central place theory and the hierarchy of cities, and that of Losch (1944), who derived an idealized hexagonal representation of market areas based on spatial competition between firms. These early contributions provided conceptual foundations for understanding the competitive bidding for sites with higher accessibility, which produces declining land rent gradients from high access locations, and the spatial separation of firms competing for market share. These frameworks, however, are insufficient to explain widespread emergence of secondary suburban centers and specialized employment clusters in the latter third of the 20th century.

A critical contribution to the theory of firm location that does address the emergence of employment clusters and centers is the concept of agglomeration economies, which describe positive externalities associated with spatial proximity to firms within the same or related industries. These agglomeration economies have been described as arising from information spillovers, local non-traded inputs, and a local skilled labor pool (Marshall, 1920). An important theoretical problem in urban economic models is that neoclassical economic assumptions include constant returns to scale, but the essence of agglomeration economies is the idea of increasing returns to scale for firms that cluster with other firms in their own or related industrial sectors (Krugman, 1991). There are offsetting forces that neutralize the agglomeration advantages of clustering as centers become large, producing opportunities for the creation and growth of suburban centers. Other relevant work on employment location has focused on transportation costs (Chinitz, 1960), the influence of amenities and governmental services and taxes (Bartik, 1991; Waddell and Shukla, 1993).

The employment location choice model in UrbanSim draws on these antecedents, bringing together the concepts of bid-rent theory, agglomeration economies, and the effects of transportation and local government policy in a discrete choice model. The model simulates location choices for new jobs created as a byproduct of economic expansion, predicted by an external macroeconomic model, and for jobs that have been predicted to move by the employment relocation model component of UrbanSim. To arrive at a choice model for employment location we assume that (1) each job belongs to a firm (whose characteristics other than industry sector remain latent) which is faced with a choice between alternative locations for the job, (2) that each location, indexed by i, has attached to it some utility, U_i, for the firm, and (3) that the location with the highest utility has been chosen (maximization of utility).

We refer to the more general concept of utility maximization rather than profit maximization, since the utility may be based largely or exclusively on expectations of profit for some sectors, but profit may represent a small or nonexistent part of the utility for other sectors, such as governmental and educational establishments. In the data we use for model estimation, we only observe the current location of jobs, and do not observe the alternative locations open to the employer before locating the job, nor do we observe the utility. We proceed with the multinomial logit assumptions for the utility (1) leading to (2).

The systematic component of the utility of a particular location (dropping the index i for simplicity in this and subsequent equations) is specified as a function of an array of characteristics at the *site* ($\mathbf{x}_S$), including the real estate characteristics (land value, residential units, commercial sq. ft., land use) and proximity of the site to freeways and arterials; characteristics of the land use mix and value (quantity of residential units, average land values, average improvement values) in the immediate *neighborhood* surrounding the site ($\mathbf{x}_N$); agglomeration economies from geographic *clustering* (employment by sector within 600 m) of firms of the same and each of the other sectors ($\mathbf{x}_C$); and multi-modal *accessibility* to labor, consumers, the Central Business District (CBD), and the regional airport ($\mathbf{x}_A$):

$$u = \boldsymbol{\beta}_S\mathbf{x}_S + \boldsymbol{\beta}_N\mathbf{x}_N + \boldsymbol{\beta}_C\mathbf{x}_C + \boldsymbol{\beta}_A\mathbf{x}_A. \tag{3}$$

The probability, P_i, represents the probability of the firm choosing location alternative i for a particular job. We estimate one choice model (i.e. one set of coefficients) for each of the 14 industry sectors shown in Table 1 on a random sample of 5000 observed jobs in each sector. To estimate the model coefficients we use data for business establishments in 1997, geo-coded to grid cells. The database links individual jobs to job spaces. The job spaces can be either nonresidential square footage, or a residential housing unit to account for home-based employment.

To arrive at a set of alternatives we allow each job in a sector to consider as alternatives all locations feasible to that industry sector. This generates a choice set containing potentially hundreds of thousands of alternatives, which would be intractable to estimate a choice model with. We use a uniform distribution to randomly sample a set of nine alternatives in addition to the chosen location and estimate a model using this random sample of alternatives. It has been shown previously that the coefficients of a choice model estimated from a random sample of alternatives, selected with a uniform distribution, are consistent, as explained by McFadden (1978) in his paper on residential location choice, which addressed a similar issue (see also Train, 2003).

Table 1
Industry sectors

Sector number	Sector description	Sector type
1	Resource Extraction	Basic
2	Construction	Basic
3	Manufacturing	Basic
4	Transport, Communications and Utilities	Basic
5	Trucking and Warehousing, Wholesale Trade	Basic
6	General Retail	Retail
7	Restaurants and Food Stores	Retail
8	Auto Sales and Services	Retail
9	Finance	Service
10	Insurance and Real Estate	Service
11	Business and Professional Services	Service
12	Health Services	Service
13	General Services	Service
14	Government and Education	Service

Since the coefficients are based on random sampling of alternatives, there are no alternative-specific constants, and no base alternative. The coefficients are therefore interpretable in terms of the direction of the influence of a variable on the utility and the probability of a location choice. The coefficients are somewhat comparable across industry sectors, since the same specification is used for all sectors, except that when certain variables are omitted from one sector's model but not another's, then some variation should be expected. Estimation results for sectors 6-10 are given in Table 2, for purposes of illustrating thew model specification and types of variables considered. Full results for all sectors are documented in Waddell et al. (2003b).

4.3.2. Residential location choice

The model of residential location closely mirrors the preceding description of employment location choice, and as it has been described previously in the literature (Waddell, 2000; Waddell and Nourzad, 2002), we abbreviate its description here. The residential location choice model predicts the probability that a household will select a location, specified by a grid cell of 150 by 150 m. Each grid cell can include zero or more housing units and households can only select cells with vacant housing. All housing units on a cell are assumed to be identical and we therefore do not assign the household to a particular unit.

Like the employment location choice model, this is a disaggregate choice model at the grid cell level, representing over 500,000 housing units over approximately 150,000 cells. As before, we use random sampling of alternatives for model estimation.

As before, the model is specified as a multinomial logit model (2) with a systematic utility for a particular location on the form:

$$u = \alpha + \boldsymbol{\beta}_{\mathrm{H}}\mathbf{x}_{\mathrm{H}} + \boldsymbol{\beta}_{\mathrm{R}}\mathbf{x}_{\mathrm{R}} + \boldsymbol{\beta}_{\mathrm{N}}\mathbf{x}_{\mathrm{N}}, \quad (4)$$

where each utility term is a linear combination of variables that have been grouped in to categories: H indicates housing characteristics (e.g. prices, density, age), R indicates regional accessibility, and N reflects neighborhood-scale effects (socioeconomic composition, land use mix, density, local accessibility).

The principal data used in the analysis is based on a travel survey conducted in the Wasatch Front region in 1997 of approximately 4000 households. This data is supplemented with housing and neighborhood information by linking the survey coordinates to the UrbanSim grid cells and retrieving grid cell values for the characteristics of housing, neighborhood, and regional access based on the traffic analysis zone containing the cell. The variables are drawn from the literature in urban economics, urban geography, and urban sociology.

The model generalizes the classical urban economic trade-off between transportation and land cost (Muth, 1969; Mills, 1967; Alonso, 1964) by including regional and local access measures, such as those of travel time to the classic monocentric CBD, travel time to airport, distance to highway, multi-modal access to employment opportunities, and local shopping. All independent variables are endogenous to the model system – that

Table 2
Employment location choice models

Model summary					
Sample size	5,000	5,000	5,000	5,000	5,000
Full model log-likelihood	−9,409	−8,761	−8,456	−8,358	−7,476
No-coefficients log-likelihood	−11,513	−11,513	−11,513	−11,513	−11,513
Adjusted ρ^2 with no-coefficients model	0.182	0.239	0.265	0.274	0.350
Variable	Coefficient (SE)				
	6	7	8	9	10
Characteristics of the cell					
Log of commercial sq.ft.	$-0.335(1.403\times10^{-2})$[a]	$-0.374(1.457\times10^{-2})$[a]	$-0.493(2.453\times10^{-2})$[a]	$-0.267(1.470\times10^{-2})$[a]	$-0.318(2.147\times10^{-2})$[a]
Log of the distance to nearest highway	$-0.024(6.906\times10^{-3})$[a]	$-0.022(6.742\times10^{-3})$[a]	$-0.049(6.928\times10^{-3})$[a]	$-0.069(7.362\times10^{-3})$[a]	$-0.092(7.334\times10^{-3})$[a]
Log of the number of residential units	–	$0.070(2.131\times10^{-2})$[a]	$0.123(2.274\times10^{-2})$[a]	$0.182(2.203\times10^{-2})$[a]	$0.135(2.222\times10^{-2})$[a]
Floor space within walking distance, by development type					
Commercial, low-density	–	$0.313(7.404\times10^{-2})$[a]	$0.973(1.896\times10^{-1})$[a]	$-0.568(8.188\times10^{-2})$[a]	$-1.058(1.865\times10^{-1})$[a]
Commercial, medium-density	$0.259(5.340\times10^{-2})$[a]	$0.475(7.178\times10^{-2})$[a]	$0.844(1.954\times10^{-1})$[a]	–	$-0.682(1.860\times10^{-1})$[a]
Commercial, high-density	$0.235(4.929\times10^{-2})$[a]	$0.355(7.558\times10^{-2})$[a]	$0.727(2.027\times10^{-1})$[a]	–	$-0.767(1.903\times10^{-1})$[a]
Group mixed use	–	–	$0.488(1.820\times10^{-1})$[a]	$-0.467(7.173\times10^{-2})$[a]	$-0.686(1.703\times10^{-1})$[a]
Industrial or governmental	$-0.508(5.333\times10^{-2})$[a]	$-0.314(7.478\times10^{-2})$[a]	$0.379(2.009\times10^{-1})$	$-1.145(5.743\times10^{-2})$[a]	$-1.796(1.965\times10^{-1})$
Jobs within walking distance, by sector					
Resource Extraction	$-0.006(5.625\times10^{-4})$[a]	$0.001(6.068\times10^{-4})$[a]	$0.004(7.163\times10^{-4})$[a]	$-0.007(4.175\times10^{-4})$[a]	$-0.002(3.877\times10^{-4})$[a]
Construction	$0.001(1.577\times10^{-4})$[a]	$-0.001(2.043\times10^{-4})$[a]	$0.000(1.545\times10^{-4})$[a]	–	–
Manufacturing	–	$0.000(6.934\times10^{-5})$[a]	$0.000(6.530\times10^{-5})$[a]	$-0.001(6.405\times10^{-5})$[a]	$-0.001(7.309\times10^{-5})$[a]
Transp./Communic./Utilities	$0.000(3.994\times10^{-5})$[a]	–	$0.000(3.821\times10^{-5})$[a]	$0.000(5.033\times10^{-5})$[a]	–
Truck./Wareh./Wholesale	$0.000(7.735\times10^{-5})$[a]	$0.000(7.618\times10^{-5})$	–	$-0.001(1.002\times10^{-4})$[a]	$0.000(9.985\times10^{-5})$[a]

General Retail	$0.002(5.026\times10^{-5})$[a]	$0.000(6.604\times10^{-5})$[a]	$0.000(7.147\times10^{-5})$[a]	–	$0.000(6.804\times10^{-5})$[a]
Restaurants/Food	$0.001(8.810\times10^{-5})$[a]	$0.002(8.567\times10^{-5})$[a]	–	–	–
Auto Sales/Service	–	–	$0.005(1.370\times10^{-4})$[a]	–	$-0.001(1.891\times10^{-4})$[a]
Finance	–	$0.000(1.015\times10^{-4})$[a]	$0.000(1.085\times10^{-4})$[a]	$0.002(5.670\times10^{-5})$[a]	–
Insurance/Real Estate	$0.000(8.718\times10^{-5})$[a]	$-0.001(7.818\times10^{-5})$[a]	$0.000(1.256\times10^{-4})$[a]	$0.000(6.108\times10^{-5})$[a]	$0.001(4.9961\times10^{-5})$[a]
Business/Professional Services	$0.000(4.585\times10^{-5})$[a]	$0.000(5.914\times10^{-5})$[a]	$0.000(6.222\times10^{-5})$[a]	–	–
Health Services		$0.000(5.919\times10^{-5})$[a]	–	$0.000(5.521\times10^{-5})$[a]	$0.000(4.479\times10^{-5})$[a]
General Services	$0.000(3.633\times10^{-5})$[a]	$0.000(3.558\times10^{-5})$[a]	$0.000(7.082\times10^{-5})$[a]	$0.000(2.389\times10^{-5})$[a]	–
Government/Education	$0.000(3.045\times10^{-5})$[a]	$0.000(2.842\times10^{-5})$[a]	$0.000(3.455\times10^{-5})$[a]	$0.000(3.053\times10^{-5})$[a]	$0.000(2.466\times10^{-5})$[a]
Other characteristics of the walk-accessible vicinity					
Log of the average land value per acre within walking distance	$-0.167(2.071\times10^{-2})$[a]	–	–	–	$0.719(5.483\times10^{-2})$[a]
Log of improvement value per residential unit within walking distance	$-0.017(8.113\times10^{-3})$[a]	–	$0.068(8.925\times10^{-3})$[a]	$-0.040(1.008\times10^{-2})$[a]	$0.038(8.417\times10^{-3})$[a]
Log of the number of residential units within walking distance	$0.158(1.449\times10^{-2})$[a]	$0.219(1.358\times10^{-2})$[a]	$0.052(1.436\times10^{-2})$[a]	$0.129(1.781\times10^{-2})$[a]	–
Log of total value of the cell	$0.247(2.982\times10^{-2})$[a]	$0.181(3.155\times10^{-2})$[a]	$0.173(3.786\times10^{-2})$[a]	$0.384(3.242\times10^{-2})$[a]	$0.292(4.038\times10^{-2})$[a]
Characteristics of the cell's TAZ					
Log of work accessibility to employment for one vehicle households	$1.729(4.789\times10^{-1})$[a]	–	$2.805(4.959\times10^{-1})$[a]	$2.991(5.161\times10^{-1})$[a]	$-0.637(3.514\times10^{-1})$
Log of work accessibility to population for one vehicle households	$-1.444(4.325\times10^{-1})$[a]	–	$-2.996(4.526\times10^{-1})$[a]	$-2.730(4.597\times10^{-1})$[a]	$0.758(3.745\times10^{-1})$[a]
AM peak hour travel time by single-occupancy vehicle to the CBD	$0.053(7.722\times10^{-3})$[a]	$0.018(6.898\times10^{-3})$[a]	$0.048(8.322\times10^{-3})$[a]	$0.125(8.099\times10^{-3})$[a]	–
AM peak hour travel time by single-occupancy vehicle to the airport	$-0.035(7.902\times10^{-3})$[a]	$-0.012(6.958\times10^{-3})$	$-0.042(8.461\times10^{-3})$[a]	$-0.112(8.208\times10^{-3})$[a]	–

[a] Significant at $\geqslant 95\%$.

is, they are predicted by other parts of the model system shown in Fig. 1, and therefore, predicted values are provided in future years for the application of the model system over periods of 30 years.

The specific variables used in the Wasatch Front model were revised based on initial testing of the integrated model, which indicated that the model needed to be more sensitive to budget constraints and to the interaction between the characteristics of the locating household and the socioeconomic composition of the neighborhood under consideration. The specification of the household location choice model includes variables representing the interaction of household characteristics and the characteristics of residential locations. Descriptive names for variables are included in the presentation of the results below. The variables used in the residential model estimation and the results of the model estimation are presented in Table 3.

4.3.3. Real estate development

The real estate development model implements the supply side of the model system to interact with the two preceding demand models of employment and household location choice as well as the land price model. Real estate development occurs as a collection of choices and actions taken by individual developers on individual sites regarding whether and how to develop or redevelop those sites. We assume their behavior is motivated by profit expectations, within constraints imposed by their resources, the physical environment, and by public

Table 3
Household location choice model

Model summary	
Sample size	2,520
Full model log-likelihood	−5,040
No-coefficients log-likelihood	−5,803
Adjusted ρ^2 with no-coefficients model	0.088
Variable	Coefficient (SE)
Indicators of the cell's development type	
Residential, density 1	$-1.190(2.276 \times 10^{-1})$[a]
Residential, density 2	$-0.822(1.385 \times 10^{-1})$[a]
Residential, density 3	$-0.593(1.002 \times 10^{-1})$[a]
Residential, density 4	$-0.351(8.667 \times 10^{-2})$
Residential, density 5	$-0.128(7.504 \times 10^{-2})$
Residential, density 6	$-0.270(8.083 \times 10^{-2})$
Other characteristics of the cell	
Total value per residential unit, divided by income	$-0.060(2.255 \times 10^{-2})$[a]
Log of the number of residential units	$-0.743(4.918 \times 10^{-2})$[a]
Income times log of improvement value per residential unit	$0.000(4.074 \times 10^{-6})$[a]
Number of residential units in the cell, given that the household has children	$-0.005(1.261 \times 10^{-3})$[a]
Indicator for a young head of household and a high-density residential cell	$0.476(9.561 \times 10^{-2})$[a]
Characteristics of the cell's walkable vicinity	
Log of residential units, given the household has no cars	$0.996(2.169 \times 10^{-1})$[a]
Log of residential units, given the household has one car	$0.842(1.016 \times 10^{-1})$[a]
Log of residential units, given the household has 2+ cars	$0.377(9.588 \times 10^{-2})$[a]
Income times log of industrial floor space	$0.000(2.866 \times 10^{-7})$[a]
Income times log of commercial floor space	$0.000(2.126 \times 10^{-7})$[a]
Log of the average land value per acre	$0.322(9.064 \times 10^{-2})$[a]
Log of residential units, times the household's size	$-0.069(1.709 \times 10^{-2})$[a]
Log of retail space, given fewer household cars than workers	$0.140(3.708 \times 10^{-2})$[a]
Log of retail space, given greater or equal household cars than workers	$0.077(1.738 \times 10^{-2})$[a]
Characteristics of the cell's TAZ	
Log of accessibility to employment, given a household with no vehicles	$0.418(1.843 \times 10^{-1})$[a]
Log of accessibility to employment, given a household with one vehicle	$0.761(2.458 \times 10^{-1})$[a]
Log of accessibility to employment, given a household with 2+ vehicles	$0.797(2.412 \times 10^{-1})$[a]
Log of accessibility to population	$-2.070(2.426 \times 10^{-1})$[a]

[a] Significant at $\geqslant 95\%$.

land use regulations such as local comprehensive plans and protection of environmentally sensitive areas. The main influences on development choices are factors influencing prices of different types of real estate at different locations, the costs of producing those development projects, and the constraints relevant at those sites.

There are two general approaches that developers consider in making development choices. The first is known as the use looking for a site, and corresponds to a specialized developer who has a specific project in mind, and attempts to find the most profitable site for the project. The second general approach is known as the site looking for a use, and corresponds more closely to the landowner's problem of sorting out which type of development construct on a specific site, that will generate the highest return (sometimes referred to as the 'highest and best use' of the site by the real estate industry. In the real world, both approaches occur. We have structured the current model as a discrete choice model from the perspective of the site looking for a use-the landowner's perspective. This approach lends itself to formulation as a standard multinomial logit model, where an individual landowner considers alternative uses, or developments, for a particular site. In subsequent research, not reported in this paper, we have implemented a development model from the alternative perspective of a use looking for a site, using the same framework outlined for the household and employment location choice models.

The purpose of the real estate development model is to simulate discrete developer choices about whether to initiate a development project at particular sites within a given year, what type of construction to undertake, and the quantity of construction. The construction of real estate can be either new development (sometimes referred to as greenfield development) or the intensification or conversion of existing development (referred to as infill and redevelopment, respectively).

The probability of each alternative (no development, increasing density of current cell within the current development type, and transitions to other development types) being chosen is calculated using a multinomial logit model. Similar approaches have been developed to model land cover change (Turner and Gardner, 1991) and land use change (Landis and Zhang, 1998), although none of these models interact with disaggregate demand-side models of residential and employment location choice as is done in UrbanSim.

To arrive at a choice model for development we assume that (1) each cell has a developer agent, (2) each development alternative, indexed by i, has attached to it some utility, U_i, for the developer, based principally on profit expectations, and (3) the development event with the highest utility has occurred (maximization of utility).

To form the estimation data we take all of the development event cells, i.e. cells with a known development event, and look up the values for a set of independent variables from the grid cell database. The independent variables in the real estate development model include characteristics of the *site* ($\mathbf{x}_S$), including current development, land use plan, environmental constraints, policy constraints, land and improvement value, and proximity to highways, arterials, existing development, and recent development; characteristics of the land use mix, property values, and local accessibility measures in the *neighborhood* surrounding the site ($\mathbf{x}_N$); and multimodal *accessibility* ($\mathbf{x}_A$), including access to population and employment and travel time to the central business district and airport:

$$u = \alpha + \boldsymbol{\beta}_S \mathbf{x}_S + \boldsymbol{\beta}_N \mathbf{x}_N + \boldsymbol{\beta}_A \mathbf{x}_A. \tag{5}$$

We proceed with the multinomial logit assumptions for the utility (1) leading to (2). The probability, P_i, represents the probability of a developer agent for a particular cell choosing development alternative i.

We now need to take into account the much larger set of cells that did not experience a development event. We take a random sample of these cells to generate a choice set of similar size as the development event set. This gives us a choice-based sample of cells. Choice-based sampling only biases the alternative-specific constants but other coefficients remain consistent (Manski and McFadden, 1981). We adjust the alternative-specific constants after estimation to account for this bias.

We estimate one choice model (i.e. one set of coefficients) for each development type, since the types are very different and the development alternatives open to each development type vary. To estimate the model coefficients we need data for cells experiencing no development and for cells with development events of all types.

The estimation data are derived from the parcel and grid data for a base year of 1997. The year-built values of the existing development in the assessor's records are the foundations of the process. Year-built values are imputed for records for which they are missing by examining the surrounding cells of the same type and drawing from the distribution of observed values. Historical development 'events' are identified in the data for a user-specified period of time. Events, within this framework, are any changes in the real estate development within a cell that is identified by examining the year built values within the data.

The procedure is capable of identifying any new construction that has a year-built occurring within the specified time frame. However, the procedure does not identify events that involve the demolition of buildings at some time in the past, since normally there is no record of demolitions within the current assessor database. This procedure could be augmented with data derived from building demolition and permit records.

The result is a set of cells experiencing development events that represent all observed transitions between any pairs of development types, including increases in density that did not result in a development type change, within each year of the specified historical time frame. The time slice for determining the existence of an event is annual, since this is the limit of the information on the vintage of real estate. For further explanations of this process, see (Waddell et al., 2003a). The real estate development model is estimated separately for cells of each development type, representing a total of 24 models. Variables used and estimation results are given in Table 4 for Development Type 5, reflecting cells that are initially developed in moderate density residential use. The estimation results for all development types are available in Waddell et al. (2003b).

4.4. Land price

Land prices represent the interaction between demand and supply sides of the model system, with prices fluctuating in response to short-term (intra-year) shifts in demand and long-term (inter-year) shifts in supply, and work in the traditional economic sense to ration scarce supply of land and clear the market in the short term. The theoretical foundations of the model of land price described here draw on bid-rent theory of land markets (Alonso, 1964; Wheaton, 1977), and on hedonic price theory (Rosen, 1974). Our approach in modeling real estate prices assumes that individual consumers and suppliers are too small in scale to manipulate prices directly, making those prices exogenous to the individual actors. Whereas this assumption could be criticized in the event of oligopolistic behavior by large-scale developers or large corporations seeking sites, it is a relatively weak assumption to impose and avoids complications arising from modeling prices as endogenous to the interaction between consumers and sellers, such as having to simulate search and auction processes, imperfect information, and oligopolistic market behavior. A second assumption is that the advantages of location, such as neighborhood amenities and accessibility, are capitalized into land values. This assumption follows from a wide consensus of theoretical and empirical work in urban economics that has consistently found that in competitive land markets, the quasi-unique characteristic of land (they are not producing any more of it, every location is unique, and housing or commercial buildings are tied to their location) implies that consumers bid for location based on their willingness to pay for locational attributes, and the highest bidder wins the use of the site and sets the market price for it (Alonso, 1964; Mills, 1967).

Rosen (1974) developed the approach of hedonic price analysis, which attempts to disentangle the implicit prices for the components of the bundle of services provided by housing (the same theory applies to nonresidential space). By regressing the sale price of housing on characteristics of the housing structure and location, we obtain estimates of the implicit prices of individual characteristics – holding other characteristics constant – despite us observing only the single price of the bundle for any individual property. These implicit prices do not, strictly speaking, represent either demand functions (willingness to pay) or supply functions (reservation prices), but rather, the composite of all of the willingness to pay and reservation price functions of all consumers and sellers in the market. Given our assumption that prices are exogenous to individual consumers or sellers, this provides a reasonable way to estimate the land price function within a given market.

Following DiPasquale and Wheaton (1996), we interpret market prices of land within a metropolitan market as consisting of two parts. The first component is a mean price level, which fluctuates around long-term trends that are driven by short-term imbalances between supply and demand of real estate, by interest rates and other development costs, and in the longer-term by overall expansion and contraction of the metropolitan economy, population, and changes in income. The second component is the relative price of land across sites within the metropolitan market. These relative prices are based on relative advantage and abundance of sites with characteristics that are valued or avoided by consumers. As these underlying characteristics and the resulting relative advantage change, so too do relative prices, as these advantages are capitalized into land val-

Table 4
Developer model 5: cells beginning as Residential, density 5

Model summary		
Sample size		8,826
Full model log-likelihood		−5,040
No-coefficients log-likelihood		−5,803
Adjusted ρ^2 with no-coefficients model		0.088
Variable	Coefficient (Std. Err.)	
	Develop, but remain density	5 Develop into density 6
Constant	–	−6.210(1.182)[a]
Indicators of the cell's plan type		
Plan type 2	$1.022(2.261\times10^{-1})$[a]	$1.022(2.261\times10^{-1})$[a]
Plan type 3	$0.965(2.819\times10^{-1})$[a]	$0.965(2.819\times10^{-1})$[a]
Plan type 4	$-0.867(4.673\times10^{-1})$	$-0.867(4.673\times10^{-1})$
Plan type 5	2.129(1.437)	2.129(1.437)
Plan type 6	$0.784(4.143\times10^{-1})$	$0.784(4.143\times10^{-1})$
Plan type 7	$0.867(2.941\times10^{-1})$[a]	$0.867(2.941\times10^{-1})$[a]
Plan type 8	$1.029(8.860\times10^{-1})$	$1.029(8.860\times10^{-1})$
Percent of cell covered by		
Floodplain	−5.592(3.676)	−5.592(3.676)
Wetlands	−7.222(3.748)	−7.222(3.748)
Steep slopes	−3.391(1.754)	−3.391(1.754)
Open space	$-2.634(7.283\times10^{-1})$[a]	$-2.634(7.283\times10^{-1})$[a]
Public space	$-1.440(4.849\times10^{-1})$[a]	$-1.440(4.849\times10^{-1})$[a]
Roads	$-1.284(1.407\times10^{-1})$[a]	$-1.284(1.407\times10^{-1})$[a]
Other characteristics of the cell		
Log of total residential units	$-0.668(7.918\times10^{-2})$[a]	$0.823(1.343\times10^{-1})$[a]
A highway exists within 300 m	$-0.522(1.016\times10^{-1})$[a]	$-0.522(1.016\times10^{-1})$[a]
An arterial exists within 300 m	$-0.139(6.735\times10^{-2})$[a]	–
Prior composition of the walkable vicinity of the cell		
Percentage of same-type cells	$-0.012(2.566\times10^{-3})$[a]	$-0.027(5.164\times10^{-3})$[a]
Percentage of residential cells	$-0.012(2.949\times10^{-3})$[a]	$-0.052(4.993\times10^{-3})$[a]
Percentage of mixed use cells	$-0.032(6.494\times10^{-3})$[a]	$-0.090(1.199\times10^{-2})$[a]
Percentage of commercial cells	$-0.023(4.825\times10^{-3})$[a]	$-0.046(8.917\times10^{-3})$[a]
Percentage of industrial cells	$-0.015(8.788\times10^{-3})$	$-0.029(1.490\times10^{-2})$
Percentage of governmental cells	$-0.025(4.347\times10^{-3})$[a]	$-0.031(7.063\times10^{-3})$[a]
Log of total land value in the cell	$0.340(3.441\times10^{-2})$[a]	$0.248(9.765\times10^{-2})$[a]
Recent development within the walkable vicinity of the cell in the last 3 years		
Transitions of the same type	$-0.038(1.515\times10^{-2})$[a]	–
Transitions to mixed use	$-0.142(4.981\times10^{-2})$[a]	–
Transitions to industrial	–	$0.522(1.356\times10^{-1})$[a]
Transitions to governmental	$0.365(8.343\times10^{-2})$[a]	$0.358(1.244\times10^{-1})$[a]
Log of commercial sqft added	$0.038(1.586\times10^{-2})$[a]	–

Note: The omitted alternative is "No development".
[a] Significant at ⩾95%.

ues. This paper focuses principally on the characteristics influencing relative prices, since these will have the greatest influence on intra-metropolitan variation in real estate development and consumer location choices.

The land value for each cell, taken as the aggregation of the land value of the parcel fragments that lie within the cell, and originating from the tax assessor's estimates of the land value of each parcel, is used as the basis for the dependent variable of the land price model. The independent variables used as predictors – essentially the same as for the real estate development model – are the characteristics of the cell, its surrounding environment, and its accessibility. A semi-log specification is used, with the log of land price as the dependent variable, as is common in hedonic price studies since it generally provides a more robust specification.

The model is a linear multiple-regression of the log of land prices, $\ln(v)$, for each cell on an array of housing structural ($\mathbf{x}_S$), neighborhood ($\mathbf{x}_N$), and accessibility ($\mathbf{x}_A$) characteristics:

$$\ln(v_i) = \alpha + \boldsymbol{\beta}_S\mathbf{x}_S + \boldsymbol{\beta}_N\mathbf{x}_N + \boldsymbol{\beta}_A\mathbf{x}_A + \epsilon, \quad (6)$$

where α is the estimable intercept term; $\boldsymbol{\beta}_S$, $\boldsymbol{\beta}_N$, and $\boldsymbol{\beta}_A$ are the estimable coefficient vectors on the housing structural, neighborhood, and accessibility characteristics, respectively; ϵ is an unobserved error term, assumed to be normally distributed with mean zero and variance σ^2.

The full set of grid cells in the study area is used in model estimation, using base year (1997) characteristics and values. As such, this is a cross-sectional estimation of the market hedonic price function, rather than an estimation of a dynamic price function. Dynamics are introduced through the process of annual changes in the characteristics of grid cells due to simulated results from the real estate development, residential location and employment location models, and the external transportation model system, all of which combine to change the characteristics of grid cells on an annual basis.

Results of the land price model show that the model explains approximately 75% of the variation in the log of land value of cells. In these results, the coefficients reported are all significant at the 95% level, and the coefficients are directly interpretable. The coefficients on the continuous independent variables that are nominal show the percentage effect on land value in a cell associated with a one-unit change in the independent variable (multiply the coefficient by 100 to arrive at the percentage change). Coefficients on variables that are log-transformed are directly interpretable as elasticities. The interpretation of the coefficient β on a dummy variable X in a semi-log regression, where the dependent variable is of the form $\ln(Y)$, is that the relative effect of X on Y is given by $\exp(\beta) - 1$, and the percentage effect is $100 \cdot \{\exp(\beta) - 1\}$ (see Halvorsen and Palmquist, 1980 for details). As usual, each coefficient must be interpreted holding all other variables constant. The variables used and estimation results are shown in Table 5.

5. UrbanSim–travel model integration

5.1. Regional accessibility

Accessibility is important for residential and employment location choice, as well as real estate development, and links land use and transportation systems. As specified in the Utah model application, separate accessibility measures are computed for each zone of origin to jobs and to population. These measures use a composite disutility of travel computed by the travel model mode choice component (after iteration within the travel model system to account for congestion effects). Access to a specific type of opportunity for a given origin is computed as the distribution of opportunities at each destination weighted by the composite utility of all modes of travel to those destinations, where the composite utility is defined as the logsum from the mode choice model for each origin-destination pair for a given auto-ownership category a. In other words, the accessibility to jobs for a particular residence zone increases as a function of the number of jobs at each destination and the ease of travelling to them. The resulting access measure A_{ai} for each location i becomes:

$$A_{ai} = \sum_{j}^{J} D_j \mathrm{e}^{L_{aij}}, \quad (7)$$

where D_j is the quantity of activity in location j (it is either the population or employment depending on if we seek the accessibility to population or employment), L_{aij} is composite utility, or logsum, for vehicle ownership category a, from location i to j, scaled to a maximum value of 0 for the highest utility interchange to avoid exaggerating the effects of outlier logsum values predicted by the travel model to have positive values.

This accessibility measure has some advantages worth noting for use in measuring land use effects of transportation in a policy evaluation context. First, it is broadly consistent with utility theory and the evaluation of consumer surplus, by using the composite utility from the mode choice logit model. Second, it allows the representation of benefits from improvements to multiple modes, and from changes in all aspects of the transportation system that have been reflected in the specification of the travel model, such as fares, wait times, and transfer penalties. On the other hand, it is also limited by the design and specification of the travel models,

Table 5
Land price model

Model summary	
Sample size	107,208
F-test	5,786[a]
R-squared	0.752
Adj. *R*-squared	0.751
Variable	Coefficient (SE)
Constant	−6.395 (0.108)[a]
Characteristics of the cell	
Sample size	107,208
Log of commercial sq.ft.	−0.067 (0.003)[a]
Log of the distance to nearest highway	0.058 (0.003)[a]
Log of the number of residential units	0.180 (0.012)[a]
Log of total improvement value in the cell	0.119 (0.003)[a]
Percent of cell covered by	
Floodplain	−0.006 (3.162×10^{-4})[a]
Open space	0.005 (2.076×10^{-4})[a]
Public space	−0.004 (2.090×10^{-4})[a]
Roads	−0.002 (2.378×10^{-4})[a]
Slope	−0.014 (2.291×10^{-4})[a]
Stream buffers	−0.010 (8.325×10^{-4})[a]
Water	−0.005 (3.738×10^{-4})[a]
Wetland	−0.010 (3.627×10^{-4})[a]
Indicators of cell development type	
Residential, density 1	−0.557 (0.034)[a]
Residential, density 2	−0.290 (0.037)[a]
Residential, density 3	−0.189 (0.041)[a]
Residential, density 4	−0.087 (0.045)[a]
Residential, density 5	−0.137 (0.047)[a]
Residential, density 6	−0.293 (0.051)[a]
Residential, density 7	−0.587 (0.055)[a]
Residential, density 8	−0.725 (0.079)[a]
Mixed use, density 1	−0.096 (0.030)[a]
Mixed use, density 2	0.201 (0.068)[a]
Mixed use, density 3	0.267 (0.052)[a]
Mixed use, density 4	0.294 (0.093)[a]
Mixed use, density 5	0.498 (0.084)[a]
Mixed use, density 6	0.113 (0.079)
Mixed use, density 7	0.220 (0.127)
Mixed use, density 8	0.702 (0.123)[a]
Commercial, low-density	0.386 (0.036)[a]
Commercial, medium-density	0.694 (0.042)[a]
Commercial, high-density	0.905 (0.045)[a]
Industrial, low-density	0.268 (0.041)[a]
Industrial, medium-density	0.271 (0.047)[a]
Industrial, high-density	0.603 (0.047)[a]
Governmental	0.113 (0.015)[a]
Variable	Coefficient (SE)
Indicators of cell plan type	
Plan type 1	−0.009 (0.021)
Plan type 2	0.476 (0.011)[a]
Plan type 3	0.677 (0.016)[a]
Plan type 4	0.565 (0.014)[a]
Plan type 5	0.806 (0.127)[a]
Plan type 6	0.565 (0.020)[a]
Plan type 7	0.386 (0.022)[a]

(*continued on next page*)

Table 5 (*continued*)

Variable	Coefficient (SE)
Plan type 8	1.628 (0.026)[a]
Plan type 9	−0.482 (0.481)
Plan type 10	−0.143 (0.042)[a]
Indicators of other discrete cell characteristics	
Cells near a highway	0.135 (0.015)[a]
Characteristics of the walk-accessible vicinity	
Log of the average total value per residential unit	−0.004 (9.549×10^{-4})[a]
Log of commercial sq.ft.	3.610×10^{-5} (0.003)
Log of the percent of development type group commercial	0.033 (0.004)[a]
Log of the percent of development type group governmental	0.055 (0.003)[a]
Log of the percent of development type group industrial	0.057 (0.005)[a]
Log of the percent of development type group mixed use	0.007 (0.004)
Log of the number of residential units	0.163 (0.003)[a]
Log of total employment	0.050 (0.003)[a]
Characteristics of the cell's TAZ	
Log of accessibility to employment for one-vehicle households	−0.828 (0.032)[a]
Log of accessibility to population for one-vehicle households	2.024 (0.036)[a]

[a] Significant at >95%.

including the fairly coarse representation of networks and zones, and the consequent limitations of these models in measuring the utility and frequency of non-motorized travel.

5.2. WFRC travel model system

The travel model system for the Wasatch Front region used in this project was based on an integration of the models from the WFRC and Mountainlands Association of Governments (MAG) MPO planning areas, and extensions to incorporate non-motorized modes. The home-based work (HBW) mode choice model is stratified by auto ownership category. As a result, composite utilities, or logsum values, were computed by auto ownership level for households with zero, one, and two or more cars. The HBW nested logit model allocates home-based work trips to modes within motorized and non-motorized nests. The model addresses the following modes:

- Drive Alone (single-occupant auto trips)
- Shared Ride 2 (double-occupancy auto trips)
- Shared Ride 3+ (auto trips with three or more occupants)
- Transit – Walk to Local Bus
- Transit – Walk to Express Bus
- Transit – Walk to Light Rail
- Transit – Walk to Commuter Rail
- Transit – Drive to Local Bus
- Transit – Drive to Express Bus
- Transit – Drive to Light Rail
- Transit – Drive to Commuter Rail
- Walk-only trips
- Bicycle trips

5.3. Coupling UrbanSim and WFRC travel models

The travel demand model system must be run iteratively with UrbanSim. The interfacing of four-step travel models with UrbanSim could be done for each simulation year, since UrbanSim runs annually, but the logistical difficulties presented by the development of annual networks and running the travel model every year would be excessive[4]. There is also not a compelling argument to require such frequent interactions, considering that the accessibilities in UrbanSim are updated annually to reflect changes in the spatial distribution of population and employment. The precipitating factors for scheduling travel model runs would seem to be of two types: (1) any significant change to transportation supply, such as new or modified facilities, level of transit service, or altered prices; or (2) cumulative congestion effects that occur due to growth and spatial distribution of jobs and population. In order to provide adequate feedback from congestion effects and to reflect major supply changes, UrbanSim and the travel models were interfaced periodically, with the intervals being no longer than 5 years. The specific interaction years used in this analysis were 1997 (Base Year), 2000, 2003, 2008, 2012, 2016, 2020, 2025, and 2030.

The logistics of connecting UrbanSim and the regional travel model, which is implemented in TP+ (Citilabs), involved creating a series of scripts to automate the extraction of data from the UrbanSim output database, reformatting of these data to the form required for Trip Generation in TP+, execution of the travel model, extraction of logsums and travel times from the travel model and inserting them into the UrbanSim scenario database, and then running UrbanSim for the time interval until the next scheduled travel model run. This process was completely automated by a script that runs UrbanSim from the base year of 1997 to the end year of 2030, interfacing with the travel model for each of the 8 scheduled years listed above. The run time from start to finish for the combined model system for a single scenario using a standard desktop computer is under 48 h.

5.4. Local accessibility

The measures of accessibility outlined above are limited in several respects. First, the measurement of accessibility depends on the travel model system, which is based on zones designed for traffic loading, and is rather coarse to represent non-motorized travel. Second, the measures of accessibility do not distinguish accessibility by personal characteristics. We attempt to overcome the latter problem by interacting the accessibility measures by auto ownership with the auto ownership of the household making location choices. We attempt to address the limitations of zonal aggregation in travel models by developing more localized measures within UrbanSim.

A broad treatment of the alternative measures of local accessibility can be found in the literature, and lies beyond the scope of the current paper (cf. Crane, 2000; Ewing and Cervero, 2001). The maximum distance that people in general will walk for daily activities (e.g. grocery shopping, restaurant) is not well defined and there is no consensus in the literature about what measure should be used for planning purposes, but the range reported in various studies is from approximately one-quarter to one-half mile. This clearly depends on local conditions such as weather, terrain, street and sidewalk configuration, and safety, in addition to personal characteristics such as age and health status (Waddell and Nourzad, 2002). In this study, we define the neighborhood scale as a radius of 600 meters, which is roughly one third of a mile. This radius is used in the spatial queries of the area surrounding grid cells, and we measure land use and quantity of employment by sector using this radius.

6. Sensitivity analysis

Based on discussion at the first Peer Review Meeting in June, 2003, a validation process was devised for this project. Lack of historical data precluded a historical validation exercise, as has been done for previous UrbanSim applications (Waddell, 2002). The process carried out in this project involved testing UrbanSim in combination with the regional travel model system on a set of scenarios that would allow exploration of the sensitivity of the model system to specified changes in policy. Note that the exercise was not designed

[4] Each run of the travel model required 2 h to complete on a standard desktop computer with a Pentium 4 CPU running at 2.6 GHz. UrbanSim required approximately one half hour per year.

to evaluate the effectiveness of these policies, but to assess the model system responsiveness to the policies. Given the objectives of the project, scenarios were selected that would provide valuable information about the sensitivity of the model system that could be used to learn more about its utility for operational planning. For ease of interpretation, the scenarios are controlled experiments, which is to say, only one significant input is changed in each one. The scenarios examined were the following, shown also on the map in Fig. 2:

- The currently adopted WFRC *Long Range Plan*, phased in over 1997–2030. This scenario served as a baseline to which other scenarios were compared.
- A *No-build* scenario that holds the transportation system constant from 1997 to 2030, but includes congestion effects. This scenario represented a typical "no-build" policy scenario.
- A *Highway Alternative* that removes from the *Long Range Plan* a major section of Bangerter Highway in southern Utah County. This scenario was intended to test the effects of remove a localized, auto-oriented project.
- A *Transit Alternative* that removes from the *Long Range Plan* the proposed Mid-Jordan LRT line (planned for the next 10 years, first LRP phase). This scenario tested the removal of a localized transit project.
- A *Parking Cost Alternative* that doubles the cost of parking in Salt Lake City. This scenario was intended to test the sensitivity of results to cost considerations.
- An *Urban Growth Boundary Alternative* that imposes a boundary limiting urban expansion. This scenario tested the effects of development constraints that would come with the designation of an urban growth boundary.
- Two *Vacancy Sensitivity Tests* on alternative values of a vacancy rate coefficient in the land price model. This was requested by the Peer Review Panel to examine the model's sensitivity to vacancy rates.
- A set of runs to examine the effects of *Random Variation* in results, using the same inputs and allowing random seeds to vary between the runs.

Due to space limitations, only illustrative results are presented here, focusing on the results related to transportation evaluation measures. Detailed results for all the tested scenarios are documented in a final report on the project (Waddell et al., 2003b). One consideration to be kept in mind when reviewing these results is that the UrbanSim outputs include no adjustments or 'K-factors' as are generally used in other land use or travel models. They are the direct results of input assumptions, data, model specifications, and estimation. The previously adopted 2030 land use forecast against which the UrbanSim LRP scenario results were compared, by contrast, had been substantially revised from the direct results of the current WFRC land use algorithms based on local knowledge and negotiation.

The first integrated scenario combining UrbanSim and the regional travel model is based on the adopted Long Range Plan (LRP). Transportation improvements are phased in within the travel model run that immediately follows the actual year of opening of the facility. In all of the scenarios examined, there were several common assumptions, allowing direct analysis of the sensitivity of the model system to a specified change in assumptions between scenarios. The common assumptions included the total population and employment in the region in each year, the model coefficients, land use plan assumptions, and all other aspects of the input data except as noted in the description of each alternative below.

In developing the input assumptions for the model, a set of development constraints are coded to reflect the interpretation of the Land Use Plan designations applied to each location. These represent the user's view of what kinds of development would be consistent with the Land Use Plan, and these constraints play a significant role in constraining the behavior in the real estate development model, essentially ruling out any development outcomes that would be inconsistent with these constraints. Among the scenarios we tested, only the Urban Growth Boundary scenario alters these constraints, by reducing development capacity outside the boundary. The development constraints, which are assumptions input to the model by the user as part of a scenario, have a prominent impact on the results. The assumptions made for the sensitivity analysis on which we report need further review and refinement before production use of the model. In particular, the residential development constraints need some refinement to better match master plans, and non-residential intensification in the existing built-up areas appears overly constrained. These are input assumptions that are relatively easy to revise.

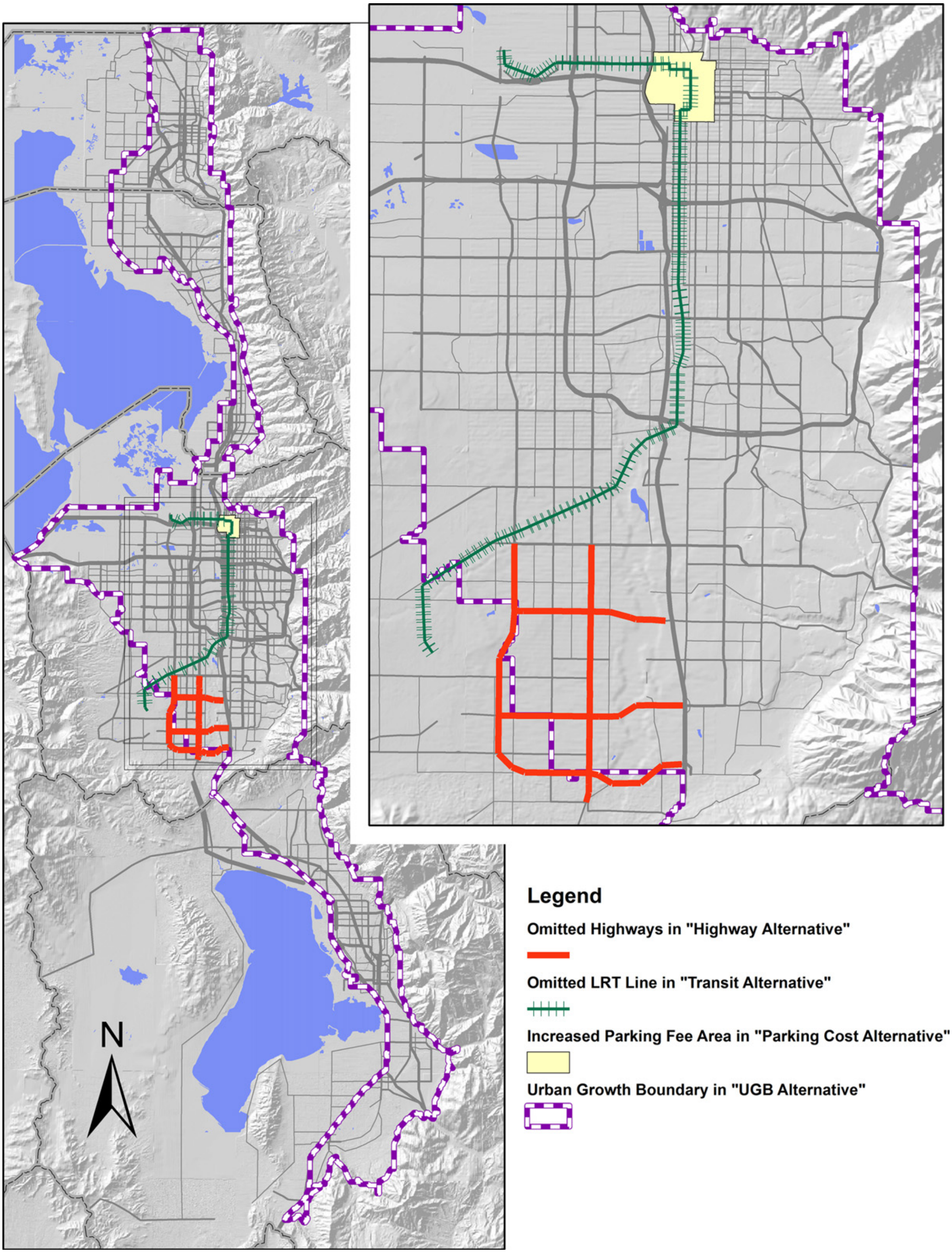

Fig. 2. Projects considered in sensitivity analysis.

Each of the scenarios was simulated using the integrated model system, with UrbanSim running every year and the travel model running in each of the years listed in Section 5. By the end of the simulation, in the 2030 analysis year, UrbanSim produced for each scenario a new geographic distribution of residential units, population, workplaces, and employment, and the geographic distributions for each of the alternatives can be compared to the LRP scenario. To illustrate, Fig. 3 shows some of the Year 2030 results of the model for the UGB scenario, with the number of households per grid cell projected in the UGB scenario compared to those projected in the LRP scenario for 2030. Note that the households are more concentrated within the Urban Growth Boundary, contributing to the modified travel patterns shown in the UGB scenario.

After running the 2030 travel model for each of the alternative scenarios tested, the results were compared using several measures of transportation performance, shown in Table 6. Some key results warrant highlighting. First, perhaps the most important element of these results is the comparison of the Long Range Plan (LRP) scenario using UrbanSim coupled to the regional travel models, to the previously adopted 2030 forecast, which was based on the same transportation system assumptions, but did not account for land use feedback effects. Accounting for these effects in the LRP scenario resulted in more than 5% higher Vehicle Miles Travelled (VMT) and Vehicle Hours Travelled (VHT) than the adopted forecast for 2030. Moreover, the Total Congestion Delay (TDC) increased by almost 16% compared to the adopted forecast. These effects are quite significant in magnitude, and confirm that the long-term induced demand reflected in the circular relationship between travel and urban development and location of activities significantly alters the evaluation of transportation system plans at a regional scale. The effects on transit mode share are relatively modest, with a slight decline in transit mode share compared to the adopted forecast. Unfortunately, these comparisons are partially confounded by slightly different control totals used in the adopted forecast, so these differences may be partially attributable to differences in those assumptions. The remaining comparisons to the LRP scenario use identical control totals for population and employment and are not subject to this concern.

The remaining scenarios are all compared to a reference case of the LRP scenario. The pattern of results for these scenarios are generally plausible in magnitude and direction, including the dramatic effects of a No-Build test in which the region doubles in population and employment but no transportation system improvements are made over the three-decade period. The No-Build scenario produces a 10% reduction in VMT compared to the LRP scenario, a 40% increase in VHT, an unimaginable 256% increase in hours of congestion delay, and a 2.3% decline in transit mode share.

Dropping selected highway projects in a rapidly growing section of Southwest Salt Lake County produces a modest −0.7% decline in VMT and VHT, as would be expected due to the induced travel effects. An interesting result was that this scenario produced a slightly larger 2.3% decline in congestion delay compared to the LRP scenario, suggesting that the location of these highway projects might actually induce more congestion due to the combined effects on land use development and travel than would be the case if they were not built. The removal of the highway project has almost no impact on the transit mode share. By contrast, the Transit scenario that reflects the omission of a light rail segment in Southwest Salt Lake County produces modest increases in VMT (0.2%) and VHT (0.5%), and a more significant increase in congestion delay (1.9%) compared to the LRP scenario. Elimination of this transit project produced a small reduction of 0.2% in the transit mode share.

The increased parking cost scenario generated 0.3% less VMT and 0.5% less VHT than the LRP scenario, along with a 0.9% reduction in congestion delay and an increase in transit mode share of 0.2%. Finally, the imposition of an Urban Growth Boundary (UGB) produced fairly substantial reductions of 3.3% in VMT, 2.3% in VHT, and 3.0% in congestion delay. Transit mode share increased by 0.2% in this scenario, compared to the LRP scenario.

These transportation effects comprise the combined effects of the land use and travel model integration, and demonstrate the sensitivity of important transportation evaluation measures to the effects of a range of changes in the transportation system and land use policies. Some of these changes were very large-scale, such as the No-Build and UGB scenarios, and these had generally clear and large effects on both land use and travel measures. The other scenarios were generally project-scale and much smaller in magnitude, and as would be expected, the effects were much smaller and in the expected the direction.

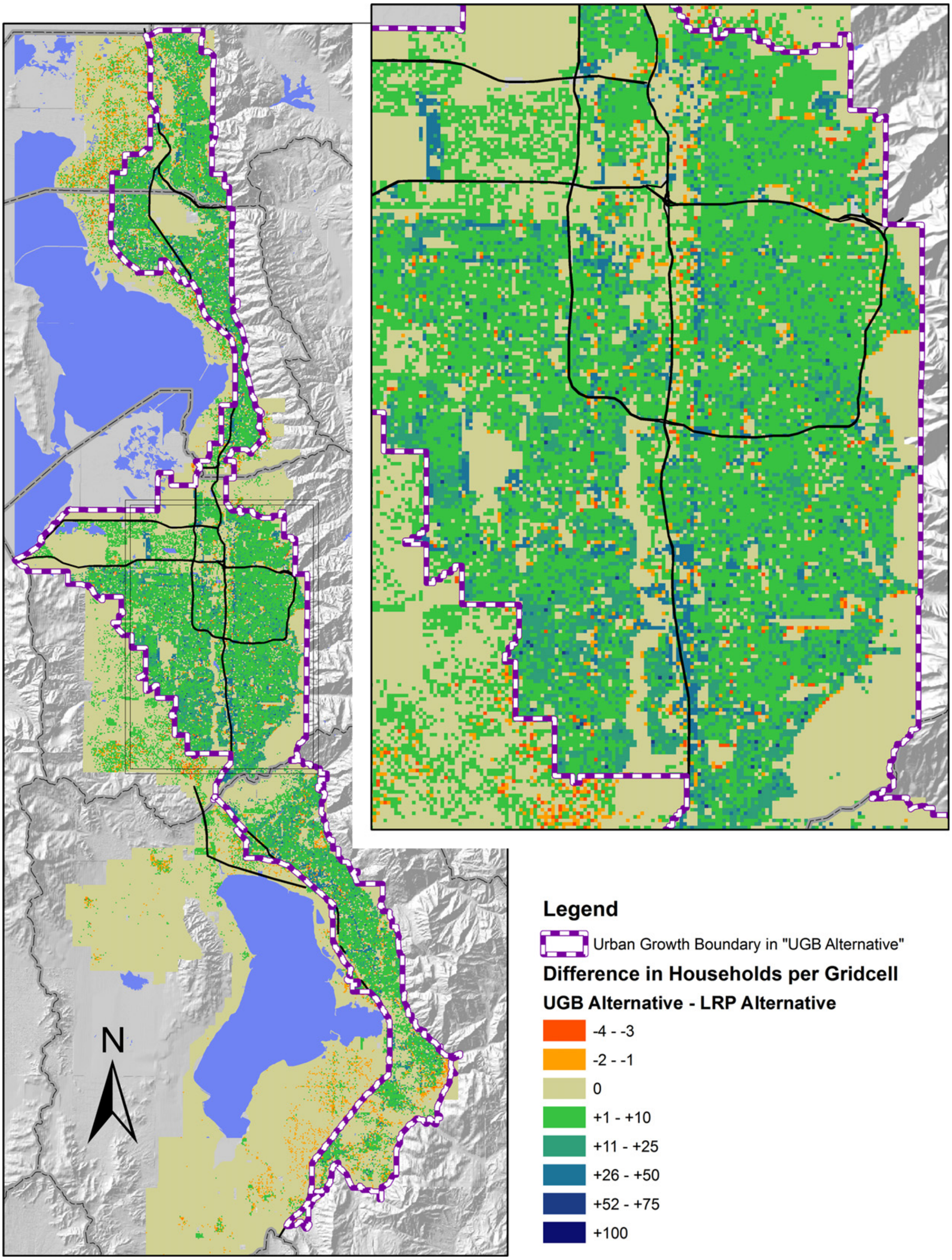

Fig. 3. Comparison of households in 2030 between UGB and LRP scenarios.

Table 6
Comparison of travel indicators across scenarios

Scenario	VMT[a] (000 s)	VHT[b] (000 s)	TCD[c] (000 s)	Transit share[d]
Base (1997)	39,403	1,095	110	2.38%
Adopted 2030 forecast	71,185	2,032	258	4.30%
Scenarios modeled with UrbanSim				
LRP[e]	75,058	2,143	298	4.26%
No-build	67,307	2,800	1,061	1.92%
Highway	74,500	2,127	291	4.24%
Transit	75,184	2,154	303	4.07%
Parking	74,797	2,132	295	4.44%
UGB[f]	72,580	2,094	289	4.47%
Comparison to adopted 2030 forecast				
UrbanSim LRP	+5.44%	+5.44%	+15.54%	−0.04%
Comparison to UrbanSim LRP scenario				
No-build	−10.3%	+30.7%	+256.4%	−2.3%
Highway	−0.7%	−0.7%	−2.3%	0.0%
Transit	+0.2%	+0.5%	+1.9%	−0.2%
Parking	−0.3%	−0.5%	−0.9%	+0.2%
UGB	−3.3%	−2.3%	−3.0%	+0.2%

[a] VMT is vehicle miles travelled.
[b] VHT is vehicle hours travelled.
[c] TCD is total hours of congestion delay.
[d] Transit share is the transit mode share for the home-based work trip purpose.
[e] LRP is the WFRC Long Range Plan.
[f] UGB is an urban growth boundary.

7. Assessment by peer review panel

Upon completion of the sensitivity analysis described above, an independent assessment of this project was prepared by the Peer Review Panel. The following are excerpts from the final report of the panel (Schofer et al., 2004):

Resource requirements – data and expertise:

> "UrbanSim is a new, complex modeling tool that demands better and different data, and considerable technical expertise for calibration and application. Additional resources in these forms are needed to support UrbanSim use in the long term. These resources applied to this modeling tool – and its successors – will bring better information to support regional policy choices. The panel encourages WFRC and its collaborators to provide these essential resources because the information increment to be gained in return is well worth the investment."
>
> "The WFRC, in collaboration with developers at the University of Washington, has demonstrated the technical ability to calibrate the modeling system and conduct validation tests. The panel is concerned that the in-house WFRC modeling and database development capabilities are stretched thin, and there appears to be little modeling expertise at the management level to direct and sustain this effort. The implementation and effective use of UrbanSim (or other integrated land use transportation models) requires an on-going commitment of staff and other resources that goes significantly beyond the resources the WFRC and other agencies in the region are currently providing. The support of the University of Washington has been essential in advancing the model to its current phase. The need for similar resources will continue into the future, and these should be secured through budgeting and contractual arrangements."

Usefulness for different WFRC applications:

> "Like many simulation models, UrbanSim needs a warm-up period of about 10 years of simulation to produce stabilized, logical results. Therefore, it will not be useful for assessing policy consequences in the

first decade beyond the date of a quality calibration data set; specifically it does not seem appropriate to expect UrbanSim to be useful for assembling the Transportation Improvement Program (TIP), at least for the next few years.

UrbanSim produced credible land use and travel results for tests of policies involving substantial changes – e.g., the no-build and urban growth boundary policies simulated to 2030 in the sensitivity tests. The panel found it difficult to interpret the outcomes of tests of narrower policies, such as the removal of substantial sections of the proposed highway or transit networks. In the latter cases, and in tests of what were thought to be radical increases in downtown Salt Lake City parking fees, results seemed almost random. It is possible that, with more experience and some model improvements, WFRC professionals and regional constituents may find it possible to use UrbanSim for smaller projects. In the meantime, the panel feels that UrbanSim is not now suitable for use for evaluating the impacts of corridor and project level actions. This will also limit its use for developing the TIP. Additional sensitivity studies, changes in model specifications, the use of smaller grid cells, and the use of fewer variables with a better calibration data set might lead to more realistic project level sensitivity in the future.''

Summary assessment:

''UrbanSim is in a class of new integrated land use-transportation simulation models intended to provide a more realistic representation of the interaction between transportation and land use: transportation systems provide accessibility that affects land use patterns, which in turn affect the performance of transportation systems. Failure to recognize this complex, cyclical, interdependent relationship may mean that important impacts of regional and local planning decisions will not be anticipated and considered. Use of such a model to support transportation planning in the Wasatch Front Region will provide more informed support for such decision making.

The Peer Review Panel supports the implementation and application of UrbanSim by the Wasatch Front Regional Commission, with the understanding that important refinements and improvements of the modeling system are needed and should be pursued to ensure its efficacy as a source of information for transportation and land use policy decision making. Given an appropriate commitment of staff and other resources, the model should be a useful tool in the short term as well as an appropriate base for improved modeling in the long term. Therefore, we believe that the most appropriate current action is to move ahead with UrbanSim, collect data to improve it, and refine it to meet WFRC needs. If done appropriately, this will generate experience and data supporting the use of this and other frameworks in the future.''

8. WFRC model refinement and operational use

After considering the Peer Review recommendations, in February, 2004 the Wasatch Front Regional Council board adopted the following resolution on the use of UrbanSim by WFRC staff:

''The Council finds that additional testing of UrbanSim is needed before the model is suitable for operational use as a planning tool. The extended testing phase will include research into model refinement, data, policy implications, estimation of resources needed, and an outreach program to familiarize planning staffs in the region on the appropriate and useful applications of UrbanSim. This resolution is taken with the understanding that the existing socio-economic forecast processes, enhanced where possible, will continue to be used to produce ''official'' socio-economic forecasts until this Council adopts another process, that may incorporate UrbanSim.''

The outcome of the peer review process was well received and resulted in the Council committing additional staff resources, including hiring a full-time land-use modeler, towards the goals outlined in the resolution. WFRC modeling staff subsequently committed themselves to taking what they learned from the review process, brought the model in-house and began refining the model to meet the Council's needs, working towards an initial goal of producing long-range socio-economic projections. To accomplish this, the WFRC staff began parallel efforts; to refine the existing model and to begin developing a more current base year database.

The peer review process was the first opportunity for the WFRC staff to run the integrated modeling system and analyze the reasonableness of the system. As the review process evolved it was clear that the outcome of the process would most likely include a recommendation to test the system further and once the WFRC staff were more comfortable with the response of the modeling system then local review would be helpful to further review the modeling system.

WFRC modeling staff had two goals for refining the modeling system that have since been accomplished satisfactorily: (1) further streamline and improve the mechanics of setting up, executing and understanding a model run; (2) simplify the statistical models by reducing the number of variables (if possible) and reviewing model coefficients for reasonableness. Further information on the specific outcome of these efforts is available by contacting the Wasatch Front Regional Council, but generally speaking, the efforts went well and underscore the need for extensive use in a beta testing mode prior to official use of the model.

Due to data limitations, it was not possible for the Council staff to conduct a standard model validation effort, back-casting from a point in time 10–20 years ago to the present day. It was clear, however, that some validation beyond the model fit statistics was necessary and so the staff made every effort to compare each sub-model's output for the base year against existing data. The land price models' output for the base year was the only model output directly comparable to observed data. The comparison that was made for the location choice models was to compare relative utilities against relative observed location patterns, making separate comparisons for separate market segments.

WFRC staff have been working to build a more current base year database and that work is nearly complete. The timing of the local long-range plan cycle and other demands have necessitated delaying the implementation of a new base-year database so as not to introduce any unknowns and delay the necessary analyses.

The first opportunity to demonstrate the usefulness of the modeling system came during the spring and summer of 2005, when the non-profit Envision Utah teamed with the MPOs in the region to conduct a regional visioning exercise and gather public feedback on a range of regional issues and discuss the dynamics of regional growth. The process overall was a success, resulting in substantially more public input to the MPO planning process than ever before. Results from the integrated modeling system were used to communicate effectively the relative trade-offs of various land-use and transportation scenarios, measuring wide-ranging impacts such as delay, transit ridership, travel time, land consumed, air quality, water quality and average lot size.

In November, 2005 the WFRC staff held another peer review of the modeling system and a draft long-range forecast with the reviewers, including local, county and state planners and economists. The outcome of the peer review was that UrbanSim is suitable for use in the planning process, and as a result UrbanSim will now be used to produce an official long-range forecast that is consistent with both long-range transportation investment priorities and local land-use policy.

9. Conclusions

The need for integrated land use and transportation modeling is clear enough. The task of developing sufficient credibility in applied models through testing and validation, and through extensive use, is a slow and arduous one. As the preceding discussion has documented, the process of advancing the state of the practice to bring integrated land use and transportation modeling into operational use has been difficult but ultimately successful. It has also demonstrated that key indicators such as vehicle miles traveled and total hours of congestion delay are significantly higher once land use effects of these transportation plans are considered, meaning that failure to account for these feedback effects exaggerates the benefits of capacity expansion. The results support the need to account for these long-term induced demand effects in evaluating transportation projects.

Much has been done since the case study reported here to refine UrbanSim, to make it easier to implement and adapt to local circumstances, and to address technical limitations highlighted by the Peer Review process. Most notable among these refinements is the development of a new Open Platform for Urban Simulation (OPUS), using a much more modular approach and a scripting language (Waddell et al., 2005). UrbanSim has now been converted to the OPUS platform and applied in the Seattle, Washington metropolitan area; Washtenaw County, Michigan; Amsterdam, the Netherlands; and Paris, France. The conversion process allowed the research team to address the specific problems identified during the technical analysis of WFRC modeling application.

The focus of current research and further development of UrbanSim and OPUS includes the analysis of uncertainty in model predictions, the development of integrated visualization, and integration of models of activity-based travel and dynamic traffic assignment. Much of this work is being done through collaboration with research teams across North America, Europe and Asia. In terms of supporting policy analysis and supporting a participatory and deliberative political process, a major thrust of new development of the system is on a web-based capacity for developing scenarios and viewing indicators from scenario results.

The obstacles to incorporating land use feedback effects in regional transportation planning are formidable. The level of effort to collect and analyze the required data is substantial, as is the effort to assess land use plans and policies, and to validate and operationalize a land use model system that integrates effectively with the current generation of travel models as well as to next-generation activity-based models. But these technical obstacles are surmountable, and mounting evidence suggests that the bias imposed on policy by not accounting for these effects is substantial.

The political and institutional context of metropolitan planning poses obstacles that may be at least as challenging as the technical ones. Control of land use policy by local municipalities is closely guarded in most US metropolitan areas, while the mandate for transportation decisions is dispersed across cities, counties, regional, state and federal agencies. Air quality is managed by yet different entities, as are water and sewer planning, and public services such as schools and public safety, all of which influence urban development and therefore travel. Coordination of these planning activities at a metropolitan scale is a critical long-term concern that reaches far beyond transportation policy, but is inherently linked with it.

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