APPLICATIONS OF INTEGRATED MODELS OF LAND USE AND TRANSPORT: A COMPARISON OF ITLUP AND URBANSIM LAND USE MODELS

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Presented at the *54th Annual North American Meetings of the Regional Science Association International*, held November 2007 in Savannah, Georgia

Abstract

The spatial distribution of regional employment and households are essential inputs to predicting transportation system performance. In this paper we compare relatively common gravity-based Integrated Transportation Land Use Planning (ITLUP)-type models to the highly disaggregate and more recent approach enshrined in UrbanSim. Land use and transportation system data from Austin, Texas provide the test-beds. The goal of this research is to find the best fit model systems for MPOs of differing resources and needs. This paper highlights the strengths and limitations of these models in the context of data requirements, calibration and presentation of results.

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1. Introduction

The interaction between land use patterns and travel behavior has been recognized in the literature for decades, but is largely neglected in practice, with the exception of a few of the nation's largest metropolitan planning organizations (MPOs), enjoying adequate resources, a particularly savvy modeling staff, or the threat of a lawsuit (see, e.g., Garrett and Wachs, 1996). The passage of two U.S. federal policies in the early 1990s, the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991, brought integrated transport and land use models (ITLUMs) from academic circles into practice (Garrett and Wachs, 1996). Passage of the most recent federal transportation bill, The Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2003 (SAFETEA), weakened incentives to integrate planning by barring judicial review of transportation plans under the National Environmental Policy Act of 1969. However, the incorporation of detailed planning metrics such as land use impacts is still seen as practically obligatory by the Department of Transportation (Gribbon and Kaleta, 2005).

Several integrated transport land use models (ITLUMs) have been applied to date and a few are publicly available at this time. This research focuses on two such models: ITLUP and UrbanSim.[1] The most widely applied land use model in the U.S. in the early 1990s (Timmermans, 2003), Putman's ITLUP relies on a gravity formulation with data aggregated to the zonal level. Regional accessibility is core to the spatial allocation of jobs and households. In contrast, UrbanSim is an open-source software developed by an interdisciplinary team at the University of Washington which seeks to simulate the development of individual parcels and the decisions of individual households and firms, or "agents," over multiple years (Waddell, 2002). It is highly disaggregate in terms of space, time, and agents, and is dynamic with constrained lags in household and business response to changes in supply of land and built space. The two ITLUMs represent the near-extreme points of the continuum between simple models with less flexibility (ITLUP) and complex models with more flexibility (UrbanSim). Miller et al. (1998) graphically depict the paths that MPOs can take to get from one end of the ITLUM spectrum (no land use model, no mode split model) to the other (fully integrated market-based model, activity-based travel model); ITLUP is described as a non-market-based land allocation model, and UrbanSim as a fully integrated market-based model (Miller et al., 1998).

The research compares ITLUP and UrbanSim and seeks to determine a best fit for MPOs with differing needs and access to resources. The two models were selected because they are relatively well documented and freely available. Several versions of ITLUP exist and the one used in this research is The Transportation Economics Land Use Model (TELUM). TELUM is the freely available counterpart to METROPILUS, a scaled-down GIS-embedded version of ITLUP (Putnam, 1983).

The remainder of this paper covers a summary of a survey of MPO current land use modeling practices and needs, background of the TELUM and UrbanSim models, and

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[1] For a review of most other tested ITLUMs, and their software, readers can turn to Timmermans (2003), Waddell and Ulfarsson (2004), and Klosterman and Pettit (2005).

comparison of the two models according to their data requirements, calibration techniques, and presentation of results.

2. Survey of MPOs

Staff members from 13 of Texas' 25 MPOs and five non-Texas MPOs were interviewed, in order to determine what methods currently are used to predict population and employment, and what methods are sought for future use. The responses varied widely, but demonstrated a clear correlation between MPO size and sophistication of forecasting methods. The state's three largest MPOs (Dallas-Fort Worth, Houston-Galveston, and San Antonio-Bexar County) already use land use models to allocate forecasted regional growth to smaller areas, such as traffic analysis zones (TAZs). The other ten Texas MPOs surveyed use simpler methods, combining Delphi process results with State Data Center control totals, Census information, Texas Workforce Commission data, and aerial photographs, in order to predict population and employment at the level of TAZs.

Most of the small MPOs have very limited staff, often only two people, and they do not feel equipped to conduct time-intensive analyses. These smaller MPOs were more likely to comment that land use modeling is unnecessary for their situation, and a few of the interviewees were not aware that such models exist. Despite small staff sizes, many of these MPOs do have Geographic Information System (GIS)-encoded data sets, particularly parcel level information (e.g., lot value, land use type) used for tax assessment purposes, available to them, although these may need major adjustment and cleaning before being used in a mathematical model such as UrbanSim.

Figures 1 through 3 offer a summary of survey results. Figure 1 shows the positive correlation between the region population and staff size. (A logarithmic scale is used here, to temper the great range in populations). Figures 2 and 3 illustrate the positive relationship between modeling method sophistication (current and future) and population and staff size. In Figures 2 and 3, "simple" refers to a Delphi process approach; "scenario" refers to the use of a visioning process or a suitability (non-forecasting) model; and "advanced" refers to a tool that forecasts and allocates population and employment to small areas/zones in a way that is well suited for input into a travel demand model (TDM).

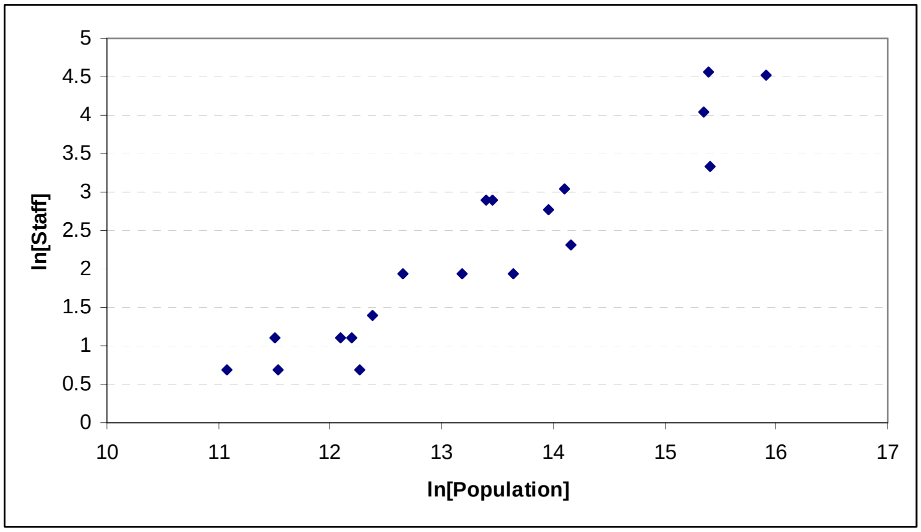

Figure 1. MPO Staff Size v. Population

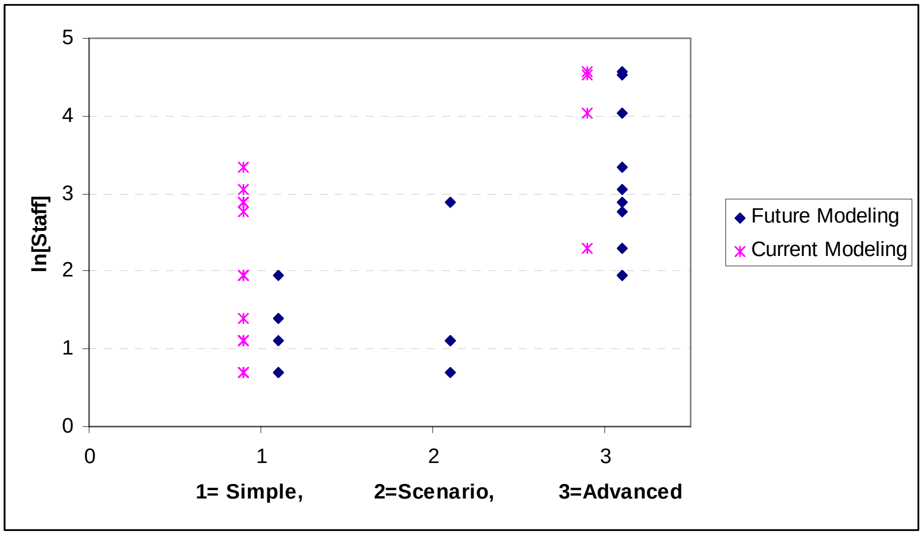

Figure 2. Staff Size v. Choice of Current and Future Modeling Method

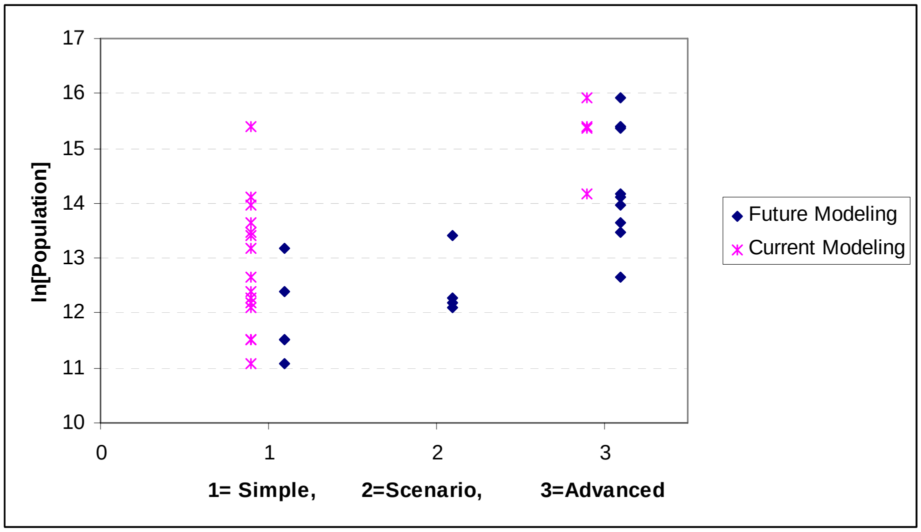

Figure 3. Population versus Choice of Current and Future Modeling Method

.These data points shown in Figures 1-3 are intuitive, since MPOs with greater resources are more able to devote staff time to implementing complex models and methods. It is clear from the synthesis presented here that, while advanced land-use models can provide detailed analysis and test the implications of policy decisions, the effort needed to implement such models may exceed the abilities of most MPOs.

3. Model Background

Before proceeding with a comparison of TELUM and UrbanSim, each model will be concisely described in this section to provide the reader with background.

3.1. TELUM

ITLUP was developed by Professor Stephen H. Putman in the early 1970s. As of 1998, ITLUP had been calibrated for over 40 regions across the world and had at least 12 active applications in the United States (Miller et al., 1998). TELUM uses the ITLUP equations to predict the location and growth of residential and nonresidential development for up to thirty years. Predictions are based on the analysis of current year and a lag year residential and nonresidential development, the locations of transportation improvements, and changes in land use conditions and interzonal travel cost over time. TELUM consists of three sub-models, namely TELUM-EMP, TELUM-RES and LANCON. The three models are explained in detail below and interact as shown in Figure 4.

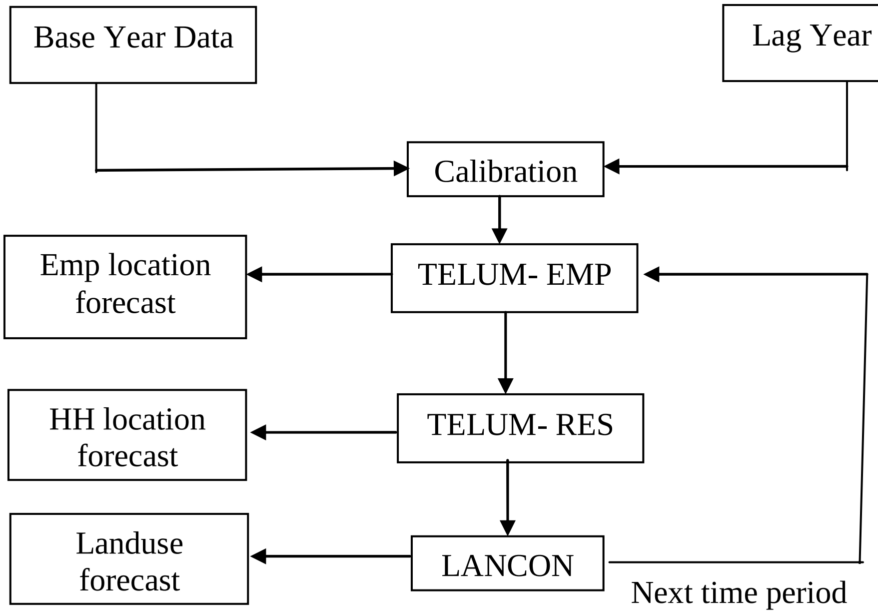

Figure 4. Block Diagram of TELUM

TELUM-EMP forecasts the future distribution of employment and was developed based on the EMPAL model of ITLUP. The number of employment sectors that TELUM-EMP can incorporate ranges from four to eight. Forecasting employment distribution is based on four factors (Putman S.H, 2007): (1) the zonal employment of a specific in the previous time period; (2) zonal households of all types in the previous time period; (3) zone size; and (4) zone to zone travel cost. TELUM-EMP also requires the total projected number of jobs in each sector in each forecast year. These control totals are used to normalize the output produced by TELUM-EMP.

TELUM-RES, developed based on the DRAM model of ITLUP, predicts the distribution of households and population in each forecast year. Households are classified into 4 or 5 groups, usually based on income. The projected spatial distribution of households is based on the current interzonal travel costs and employment distribution, as well as the following current characteristics of each zone: number of households of each type; area of land used for residential purposes; percentage of developable land that has already been developed; and vacant developable land (Putman S.H, 2007).

LANCON computes the amount of land consumed in each zone based on the assigned residential and employment distribution and the developable (supply) land in that zone[2]. The user must input the amount of land area in each zone that falls in each of the following categories: total; usable; unusable; used for basic employment; used for commercial employment; residential; used for streets and highways; and vacant developable.

TELUM has several restrictions that cannot be overcome due to its “black box” nature. Fist, the model is limited in the geographies it can consider by restrictions on the average population per zone, which must lie above 3000 (and is recommended to be below 10000). Second, the documentation is incomplete, neglecting to cover the details of the LANCON model and the calibration process. This makes tracking potential problems in predictions difficult. To overcome these restrictions, the research team developed a code following the ITLUP equations outlined in the User’s Manual (2005). This code will not be detailed here due to space constraints, but it will be made publicly available in the near future.

3.2.UrbanSim

UrbanSim, open-source software developed at the University of Washington by a team led by Dr. Paul Waddell, is perhaps the most comprehensive land use modeling package available. Eight models are used within the UrbanSim package to predict the household, employment, and land characteristics for each 150 square meter grid cell covering a region. While its comprehensiveness is attractive to many land use modelers, others are deterred by the numerous data requirements.

UrbanSim uses Census data, specifically household data from the Public Use Microdata Sample and the Summary Tape File 3A, to synthesize a base year household database with characteristics including household size, income, number of vehicles, and number of workers. Base year employment must be geocoded and assigned to grid cells with characteristics such as employment sector and number of employees. A base year parcel-level map of land cover with data on lot price, building price, land use code, and zoning must be available in GIS.

The models used in UrbanSim can be categorized into accounting models, probabilistic choice models, and regression models. Accounting models include the household and employment transition model. The household transition model simulates births and deaths using factors such as household income, age, household size, and the presence or absence of children. Created households are not assigned to a specific location until the implementation of the household location model. The employment transition model uses a similar methodology to model job creation and loss (Waddell, 2002).

Probabilistic choice models can be further broken down into rate-based models for use in relocation and logit models for use in location. The household relocation model uses historical data to simulate whether or not a household decides to move. Each household that has made the decision to move is then assigned using the household location model and the status of its

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[2] It is not clear how LANCON works in terms of calibration and projection because the TELUM manual does not provide LANCON’s formulation.

previous location is updated to vacant. The multinomial logit household location model is a function of the characteristics of the location (i.e., housing price, density, and age), neighborhood characteristics (i.e., land use mix, density, average property values, and accessibility to stores), and accessibility to jobs. The employment relocation and location models use a similar methodology to simulate the movement of jobs. (Waddell, 2002)

The land price model is a linear regression model for determining the price of each grid cell over time. It is based on urban economic theory, which states that the more valuable a piece of land is, the more expensive it will be to purchase. The value of the land is determined by neighborhood characteristics, accessibility measures, and policies.

One advantage of UrbanSim is that it allows users to create and test different scenarios based on alternative policies by changing modeling constraints. The outputs of UrbanSim can be summarized at any level of aggregation including grid cells, TAZ, or the entire region. While several metropolitan areas are experimenting with UrbanSim, it has yet to be fully implemented anywhere for official forecasting purposes.

4. Comparing TELUM and UrbanSim

TELUM and UrbanSim were selected for comparison because they are freely available, documented, and represent the near-extreme points of a tradeoff between simple models with less flexibility (TELUM) and complex models with more flexibility (UrbanSim). The two models are compared based on three criteria: data requirements, calibration, and presentation of results.

4.1. Data Requirements

The data requirements of TELUM and UrbanSim are shown in Tables 1 and 2, respectively, along with the sources from which the data was gathered for the Austin application. The data required for TELUM is typically readily available from MPO travel models and forecasts, the U.S. Census, and county appraisal districts or other sources for land area by type. Travis County appraisal district (TCAD) data does not include tax-exempt properties, so land area and type information for outside the City of Austin may incorrectly list government land and other non-taxable parcels as vacant land or another incorrect type. The City of Austin keeps a GIS layer that builds on the TCAD data and includes parcels used for all purposes.

Table 1. TELUM Data and Data Sources

TELUM

Data	Source
Population Control Totals	MPO
Employment Control Totals [by sector]	MPO
Households [by income, zone]	MPO, U.S. Census
Employment [by sector, zone]	MPO
Interzonal Travel Cost	MPO travel model
Average # employees [by household type]	Assume uniform distribution of employees across household types
Zonal Land Area - Total, Usable, Unusable, Basic employment, Commercial employment, Residential, Streets/highways, Vacant developable	Appraisal district, City land use GIS data
Regional Rate of Employee Commutation	TELUM default
Households [by income] *per Employees* [by sector]	Assume uniform distribution of employees across household types

The data needed to run UrbanSim (version 4.0) is much more extensive than that required for TELUM. Base year data is required for each job, building, and household in the region. Disaggregate data is typically available for jobs; however in many regions it may not be geocoded and may contain many errors. The Austin area MPO provided the research team with a geocoded employment dataset that was cleaned using address locating techniques. Most MPOs collect some level of employment data for use in trip generation but, as discussed by Waddell et al. (1998), this data is often insufficient and only covers categories such as warehouse, office, and industrial, at an aggregate level.

Building data is not explicitly available for Austin, so any parcel with a positive improvement value was considered to have a building on it with the type determined from the parcel's land use code. The square footage of each building was calculated based on an assumed cost of construction and the improvement value; however improved estimates could likely be made based on neighborhood specific costs.

The region analyzed was broken up into 150 meter by 150 meter grid cells, and GIS was used to translate the parcel level data into grid cell data. To alleviate the difficulties associated with this translation, UrbanSim version 4.0 allows for parcels to be used as the major unit of analysis or any other desired geography. The advantage of grid cells is that they do not change over time, while parcels may be subdivided or combined.

Table 2. UrbanSim Data and Data Sources

Data Table Name	**Data**	**Source**
Target Vacancy Rates by Year	Residential and non-residential	Borrowed
Annual Employment Control Totals	Total	MPO
	Proportion home-based	U.S. Census
Annual Relocation Rates for Jobs	[by sector]	Borrowed
Jobs	Location, sector	Texas Workforce Commission (address matching and other checks done by MPO)
	Building type	Appraisal District
	Home-based	Assumed to be home-based if located in a residence
Buildings	Type, Location, Improvement value	Appraisal District
	Area	Divide improvement value by an assumed cost of construction per unit area
	Residential units, Year built	U.S. Census
Gridcells	Distance to arterial/highway	Transportation network obtained from MPO, Distance calculated in GIS
	Residential land value	Appraisal District
	Residential units	Tract level data obtained from U.S. Census
Annual Household Control Totals	[by age of head of household and income]	MPO
Annual Relocation Rates for Households		Borrowed
Households	Persons, Workers, Age of head, Income, Children, Race, Cars	Household synthesis using U.S. Census data
	Location	Randomly assigned to residential space within TAZ
Race Names		U.S. Census
Constants	Walking distance, Young age, Ratio of total property value to annual rent, Line distance from a cell centroid to an arterial/highway for it to be considered nearby	Borrowed
	Fraction of low/mid income households	U.S. Census
Travel Data	Interzonal transit logsum, Travel time in AM peak	MPO travel model
Zones	Travel time to airport, Travel time to CBD	MPO travel model

As shown in Tables 1 and 2, the data needed to run UrbanSim is much more extensive and less readily available than the data needed for TELUM. UrbanSim data can be retrieved, but requires a much more consistent and deliberate effort on the part of the MPO and any other agency involved in the relevant data collection. If multiple agencies are involved, collaboration is critical to synchronize the time periods during which data is collected. For instance, in the Austin application, adjustments had to be made to combine data from the 2000 U.S. Census with parcel land use data that was collected in 2005. Smaller MPOs with not enough resources to keep an updated parcel level database may be more inclined to use a simpler model such as TELUM.

4.2. Model Calibration

The three terms - estimation, calibration, and validation - are sometimes used somewhat casually and interchangeably, but here they convey distinctive meanings. *Estimation* is the process of finding model parameters that best fit the observed data. For example, household surveys and transit on-board surveys typically are used to estimate the coefficients in a mode choice model, using a multinomial logit (MNL) specification and maximum likelihood estimation techniques. When surveys are not available and estimation is not possible, such coefficients may be borrowed from other regions. The distinction between model estimation and model calibration is not always so clear, and TELUM actually refers to its estimation process as a calibration process. In practice, most modelers refer to *calibration* as the process of adjusting the estimated model parameters until model outputs match a second set of observed base year travel data, such as link flows, regional vehicle-miles-traveled, and total transit system ridership (Wegmann and Everett, 2004).

The third process, *validation*, examines a model's ability to predict future patterns of observed behavior. It thereby relies on at least two time periods worth of data. For example, land use conditions in 2000 and 2005 are given, so that 2000 can be used as the base year, in order to predict year 2005 conditions – and then compare these to actual year-2005 conditions.

Calibration and validation rely on distinct data sets – past or "lag year" data, in the case of original model calibration, versus the most recent data available to the planning agency, for model validation, which is ideally followed by further model calibration. Calibration emphasizes adjustment of model parameters, while validation emphasizes evaluation of a model's predictive capabilities. They can occur in concert (iteratively), as differences between observed and predicted values during the process of validation signal the need for further calibration (Wegmann and Everett, 2004).

The Federal Highway Administration's Travel Model Improvement Program (TMIP) has produced valuable documentation on validation (Barton-Aschman, 1997) that recommends validating model results after each step or stage of the model (e.g., a parcel subdivision model, followed by a land use change model, followed by a model of parcel intensity [jobs and housing, for example]). Comparing results after each model step facilitates the discovery of any discrepancies, along with sub-model calibration. TMIP documentation describes four common measures for quantifying such discrepancies: absolute difference (estimated minus observed values), relative difference (normalized absolute differences [such as average percentage mis-prediction]), correlation (i.e., r-squared between actual and predicted values [such as population across all zones]), and variance or standard deviation in residual errors (i.e., percent root mean squared error [RMSE] between actual and predicted values).

Estimation, calibration, and validation can be time-consuming and expertise-requiring processes, making them critical to consider when determining the best fit ITLUP for a MPO. Both TELUM and UrbanSim have built in estimation techniques that will be discussed in this section.

4.2.1. TELUM

TELUM uses a gradient search technique referred to as 'CALIBTEL' to determine the optimal parametric values in the TELUM-EMP and TELUM-RES sub-models. Linear regression is used to determine the parameters in LANCON sub-model. TELUM does not allow users to fine-tune its parameters, so further calibration simply is not feasible. Essentially, TELUM-EMP and TELUM-RES solve the following entropy maximization formulation to determine the parametric values. This formulation is consistent with the theory given in Putman (1992).

$$\max \sum_{i \in I} N_i \ln\left(\hat{N}_i\right) \qquad (2)$$

$$s.t. \sum_{i \in I} N_i = \sum_{i \in I} \hat{N}_i \qquad (3)$$

where *I* is the set of all zones, N_i is the count (of jobs or households) in zone *i*, and $\hat{N}_i$ is the estimated value (of jobs or households) in zone *i*. The vector $\hat{N}$ is defined by a set of equations as described in Appendix A of the TELUM User's Manual (TELUM, 2005). Equation 3 ensures that the sum of the projected values is the sum of actual values.

The ITLUP equations are non-linear, so a global optimal solution cannot be guaranteed. TELUM's user manual does not explicitly state this instability, but a Matlab code developed by the research team, essentially replicating the ITLUP process, suggests the instability could be significant. The Matlab code converted the formulation above to an unconstrained problem by normalizing all the predicted values by the ratio of sum of actual value to the sum of the predicted values. Converting the formulation in this way, allows it to be solved with the "Nelder-Mead" method (Nelder and Mead, 1965). Several starting points are used to increase the possibility of achieving a global optimal solution. TELUM's user manual does not describe CALIBTEL in detail, but it is likely that a single starting point is used.

4.2.2. UrbanSim

UrbanSim version 4.0 is designed to estimate the coefficients of nearly all necessary choice functions and regression models. Calibration (outside the model software) then consists of using longitudinal data to check prediction reasonableness. A subset of the base year household and employment data is used for estimation of UrbanSim's over-1000 parameters. The number of parameters to be estimated will differ by region, and depends on such factors as the number of development types and employment sectors. For example, the Eugene, Oregon application for the 1980 base year has 1865 estimated parameters. The estimation routines output meaningful information on R^2 and log-likelihood values, standard errors, and p-values, along with the coefficient estimates (UrbanSim, 2007).

Four of UrbanSim's sub-models contain parameters that are not covered in the built-in estimation procedures. These models are shown in Table 3, along with suggestions of simple procedures for calibrating the parameters listed in the "Alter" column. To calibrate each entry in the "Alter" column, one can calculate the corresponding variables in the "Calculate" column and alter the appropriate "Alter" variable until the calculated quantity is considered reasonable and/or matches available data. These ideas are discussed in more detail below.

Table 3. Calibration of UrbanSim: 4 Key Models

Sub-model	**Calculate**	**Alter**
Household Location Choice	population densities by zone	household relocation probabilities, P(h,t)
Employment Location Choice	employment densities by zone	employment relocation probabilities, P(j,t)
Real Estate Development	densities of new development	construction costs, H, S demolition costs, D
Land Price	average price per zone	vacancy rates, V α δ β

The household and employment relocation probabilities, P(h,t) and P(j,t), represent the probability that a household of type h or a job of type j will transition in time period t. These probabilities are initially used in the demographic and economic transition models, respectively, to ensure that control totals are met. Hard construction costs (H), soft construction costs (S), and demolition costs (D) are parameters used in the real estate development sub-model to determine the utility of each zone for each type of development. Current and long-term structural vacancy rates (V), as well as three parameters (α,δ,β) are used within the land price sub-model to determine the price of development type i in location l at time t. For more details on UrbanSim's sub-models, see (UrbanSim, 2007).

The UrbanSim development team is presently developing an alternative model calibration method, called Bayesian Melding (BM). BM begins with prior probability distributions for the base year (y_1) input parameters based on historical data, and also a subsequent year (y_2) of data for comparison with model outputs (Sevcikova et al., 2007). Monte Carlo simulation produces model outputs in y_2 for numerous realizations of the y_1 input parameters and random number seeds. Weights are assigned to each model run based on the likelihood of the outputs given the actual y_2 data. For each parameter realization and random number seed, the model is then run until a third and future year, y_3, is reached; and the weights are used to form a probability distribution for each output measure. The model is considered to be "calibrated" if the actual data for y_3 consistently falls within a confidence interval (e.g., 90%) of the output probability distribution (Sevcikova et al., 2007).

UrbanSim 4.0's built-in estimation tools provide a great convenience to users who would otherwise have to rely on statistical software and would need to have expert knowledge of the estimation process. Although the BM process is not yet ready for public use, its development is a step in the right direction for the LUM community; treatment of uncertainty in model inputs is critical to determining the range of feasible futures that a region may experience. A coherent expression of model uncertainty can better inform planning and policy making, and lead to decisions that work well under a host of potential future outcomes.

4.3. Presentation of Results

Both TELUM and UrbanSim have the capability to display results graphically. TELUM is tied to a GIS program called MAP-IT, which will provide the user with figures displaying the intensity and density of employment, households, or population by type for a given base, lag, or forecast year. Figure 5 illustrates this capability, and shows the intensity of basic employment in the three county Austin metropolitan area for each of the forecast years (every five years from 2010 to 2030).

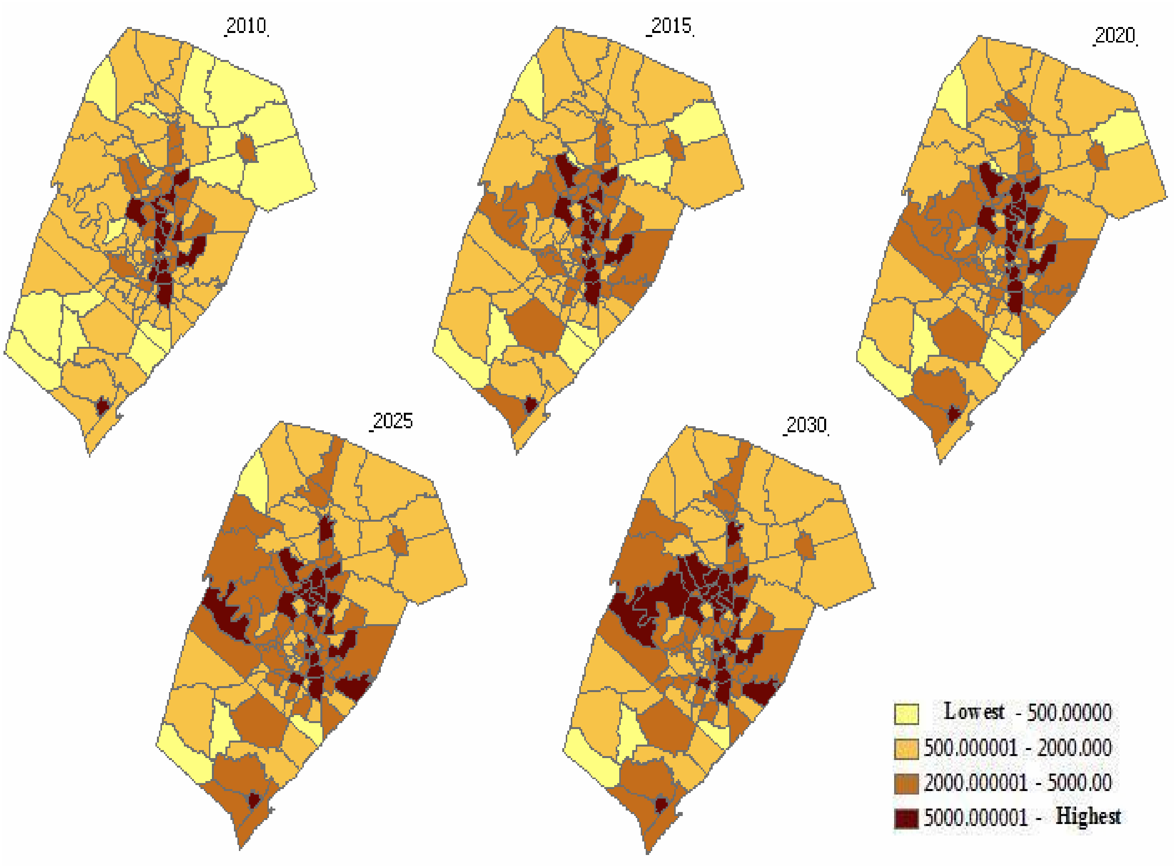

Figure 5. TELUM Forecast by District of Basic Employment

TELUM predicts that the basic employment will increase in almost all the zones in the three-county region. The basic employment is predicted to be high in the region’s outskirts, particularly in the zones west of the city by 2030.

UrbanSim offers much more flexibility in presenting model results. Users can develop numerous indicators at any defined level of aggregation. Options are available to create maps, charts, tables, and Lorenz Curves to depict equity (e.g., income equity across households). Figure 6 is a map of vacant commercial job space for a 3mile by 3mile section of Austin, chosen for its proximity to highways and diversity of development types. While some confidence with coding in Python is desired for developing an indicator, the UrbanSim user community shares indicators via its website. A small area was used for the UrbanSim application presented in this paper because it makes model testing and results analysis easier. The research team is currently preparing for a region-wide application so that the results of UrbanSim and TELUM can be directly compared.

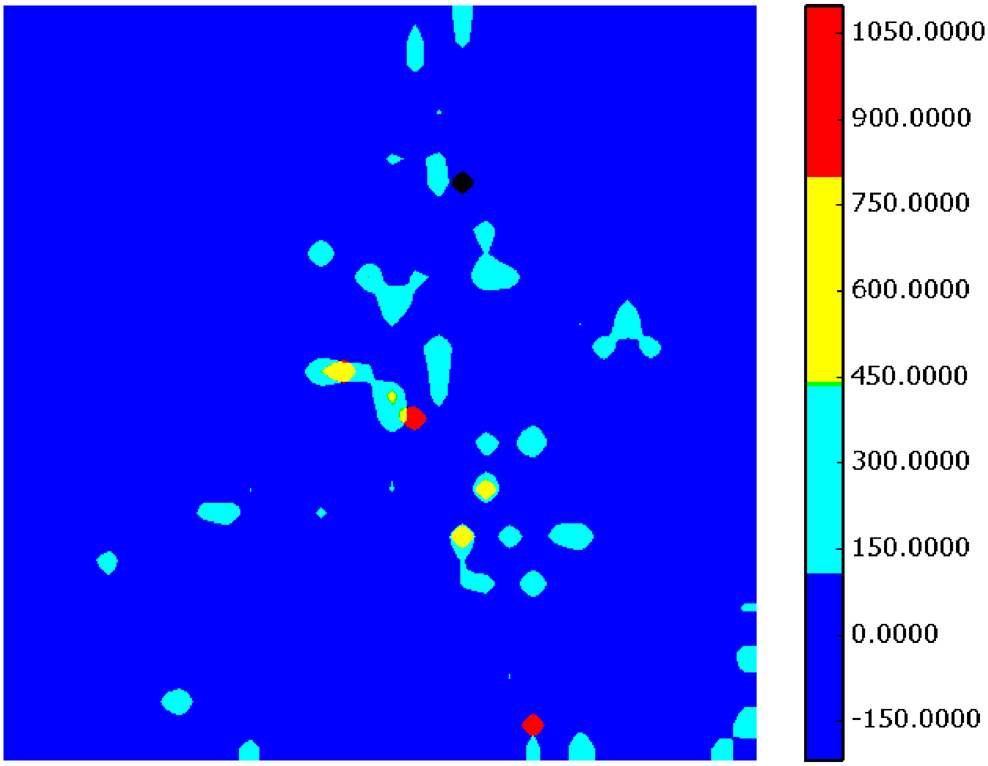

Figure 6. UrbanSim Display of Vacant Commercial Job Space for Austin Sub-area in 2007

5. Conclusions

Two land use models, TELUM and UrbanSim, were compared in this research based on three criteria: data requirements, calibration, and presentation of results. These models represent the near-extreme points of a tradeoff between simple models with less flexibility (TELUM) and complex models with more flexibility (UrbanSim). A direct comparison of results is not possible because the analysis regions differed for the two models, in part due to the complexity of UrbanSim. The goal of this research is to find the best fit model systems for MPOs of differing resources and needs.

The highly aggregate data required for TELUM is relatively easy to gather and should be readily available at most MPOs. The disaggregate data required for UrbanSim may take months or even a few years to refine to an acceptable level of reliability. It could be argued that the disaggregate model with imperfect data may still perform better than the aggregate model with perfect data; however it is difficult to test such a hypothesis unless cross-sectional data is available for both model types.

The difficulties in finding and refining data for UrbanSim for one year mean that full calibration may not be possible, since such a process typically requires two years of data. The Bayesian Melding calibration method under development by the UrbanSim team requires two or more years of data. However, as disaggregate models become more popular and the techniques for gathering and cleaning the required data are refined, cross-sectional data may become more abundant. The data required for TELUM calibration is more readily available, but the process that is used is not fully documented and the researchers suspect that CALIBTEL will rarely find a global optimal solution.

Despite the difficulties that UrbanSim's data requirements pose on building a model and calibrating it, once the data is ready and the model is run there are numerous options available for presenting the results. Modelers can develop indicators to present results that are specific to the audience and the project. Indicators developed by individual MPOs or research teams can be easily shared with the UrbanSim community, providing great benefits. TELUM, on the other hand, is very limited in its presentation capabilities. It is tied to a GIS mapping tool, but can only present results at an aggregate level, making policy decisions based on the results difficult or impossible.

Overall, UrbanSim is recommended for MPOs that have sufficient resources and time to devote to data gathering and cleaning, and that need to answer policy questions that simply cannot be answered using an aggregate land use model. An aggregate model similar to TELUM is recommended for small MPOs that are new to land use modeling and need land use forecasts to input into a travel model. In the near future, the research team will make an open ITLUP code available to the public that uses the equations in the TELUM documentation with a refined calibration procedure and relaxed data input constraints.

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