UNCERTAINTY PROPAGATION IN LAND USE-TRANSPORTATION MODELS

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ABSTRACT

This study examines the impact of uncertainty in the land use component of two semi-integrated land use-transportation models. Outputs from the land use models (LUM) act as inputs for travel demand models (TDM), and travel times from the traffic-assignment stage of the TDM are fed forward into the subsequent year’s LUM. This work examines the propagation of uncertainty across model stages as well as at each model stage over time. Monte Carlo methods and factorized design methods are used to simulate uncertainty in demographic inputs to the land use models, as well as uncertainty in various model parameters. Many of the conclusions of the study are consistent with the widely held belief that inaccurate socioeconomic projections are a significant source of uncertainty in land use-transportation models. However, some of the results appear to contradict previously held beliefs, since they suggest that model parameters may have as significant an impact on model outputs as socioeconomic projections. However, there is a distinct possibility that these results are an aberration caused by the data used to calibrate the land use model, or the relatively few simulations performed. In the case of UrbanSim’s model, with appropriate constraints on residential and employment density and land use, the level of uncertainty in outputs appears to decrease in later years as the system being modeled approached saturation. In basic application of ITLUP without density constraints and land use restrictions, the level of uncertainty in model outputs increases in successive years and responds substantially to calibration parameters rather than population and employment levels.

1 INTRODUCTION

Previous studies have shown that transportation planners often do not recognize the uncertainty implicit in modeling a complex and dynamic urban system (please see Mehndiratta et al [2000] for a discussion of how issues related to uncertainty are presently addressed in metropolitan planning organizations). Typically, static models are used to predict discrete values of travel demand, mode shares, and traffic volumes on links (Niles and Nelson, 2001). Uncertainty present in earlier model stages also tends to compound itself over later stages, when model stages are developed sequentially (Zhao and Kockelman, 2001).
The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 requires that metropolitan and statewide transportation plans be integrated with land use plans (Miller et al., 1999). However, few studies in the past have examined uncertainty propagation in the context of an integrated land use-transportation modeling framework.

The objective of this study is a better understanding of uncertainty in demographic and other inputs on urban development, how this uncertainty is propagated through the stages of an integrated land use-transportation model, and how uncertainty evolves over time. This has been accomplished by outlining a general method of uncertainty analysis that can be applied to a variety of land use-transportation models. The results of applying this model to UrbanSim (Waddell et al., 2001) and ITLUP (Putman, 1983) are presented along with certain conclusions, some of which are generic to many such models. These two models were chosen because they are two distinct examples of urban land use-transportation modeling systems in the United States.

2 CURRENT APPLICATION

Of the many sources of uncertainty that may affect the predictions of land use-transportation models, not all can be dealt with empirically (Mahmassani, 1984). This study primarily considers only those sources of uncertainty deemed amenable to empirical analysis. Uncertainty in model outputs can be attributed to uncertainty in model inputs (for example, population and employment forecasts) and/or uncertainty in model parameters (for example, coefficients in a trip generation model). This study proposes to examine the impact of, and quantify the sensitivity to, both of these sources.

This work examines the impact of uncertainty in the land use component of an integrated land use-transportation modeling system. Here, outputs from the land use model (LUM) act as inputs for a traditional 4-step travel demand model (TDM); and where travel times from the traffic-assignment stage of the TDM are fed forward into the subsequent years LUM.

The current application uses the Eugene-Springfield dataset, which was provided by the University of Washington. The Lane Council of Governments (LCOG), a voluntary association of local governments in Lane County, Oregon that facilitates multi-jurisdictional planning and program development, provided the Eugene-Springfield network, which comprises 2970 links. The base year for the Eugene-Springfield database is 1980, and data from a home interview survey and from the census were adjusted to the base year using the parcel-level distribution of housing stock in the base year.

2.1 Analysis Using UrbanSim

Inputs to UrbanSim that were considered for variation were the aggregate population and employment growth rates, household and employment mobility rates, and parameters in UrbanSim’s location choice and land price models. Growth rates and mobility rates were varied from a high of 1.5 times, to a low of 0.5 times the default growth rate. Together with the mean, these represent three well-distributed sample points. A factorized design approach outlined earlier was adopted in sampling model parameters, wherein the input distribution was divided into three equal-probability bins, and the mid-percentile point of each bin was chosen as the sample point. In all, 81 combinations of the variations, or 81 scenarios have been modeled.
The outputs of both the land use and the travel demand models were considered for analysis. Outputs of the land use model that were examined in detail here are land prices, occupancy rates and occupancy densities. Occupancy rate (Occ. Rate) is defined as the proportion of available dwelling units that are occupied by households or jobs. Occupancy density (Occ. Dens.) is defined as the proportion of available developed area that is used. Outputs of the travel demand model that were examined include the vehicle miles traveled (VMT), the vehicle hours traveled (VHT), and the average of flows on a few individual links.

In the long run, only population and employment growth rates appear to have a significant impact on all model outputs. One possible explanation for this could be the fact that only population and employment growth rates have an impact that is cumulative. In the long run, the cumulative effects of differences in growth rates appear to overshadow all other differences. This is also reflected in the frequency distribution of model outputs, which are split into distinct groups on the basis of differences in growth rates.

The evolution of uncertainty in UrbanSim’s outputs is depicted in Figure 1. The level of uncertainty (as measured by the coefficient of variation [COV], which is defined as the standard deviation of a variable divided by its mean) appears to go up in the initial years for which the model is run, but then goes down. This is a trend that is consistently reflected in all outputs of both the land use and the travel demand model. This may be because changes in input data cause shocks throughout the urban system being modeled, and these shocks build up in the initial years for which the model is run. These shocks are caused by the fact that changes made to the input data may be in discord with existing model conditions. As households, jobs, and developers respond to the changed input conditions (via their respective models), these shocks are dampened, resulting in a lowered level of uncertainty in later years.

Significantly, outputs of the travel demand model appear to be far less variable than outputs of the land use model. It is hypothesized that this may be a direct consequence of the traffic assignment procedure employed, which is the Stochastic User Equilibrium (Sheffi, 1984; Sheffi and Powell, 1982) assignment. The SUE procedure attempts to find an equilibrium in traffic flows through a large number of iterations, which may have the effect of reducing the variability in link flows, and hence in total VHT and VMT.

2.2 Analysis Using ITLUP

In order to facilitate comparisons between ITLUP and UrbanSim, ITLUP’s models were calibrated using the Eugene-Springfield dataset. The zonal level data required to calibrate ITLUP was derived from two consecutive years’ predictions in UrbanSim. Household totals by income category were obtained by aggregating UrbanSim’s nine income classes into 4 relatively homogeneous bins (viz. low, low-medium, high-medium and high). Similarly, employment totals by sector were obtained by aggregating UrbanSim’s 14 employment classes into three aggregate sectors (viz. basic, retail and service).

Inputs that were varied include the aggregate population and employment growth rates and all model parameters in each of the 3 employment sectors in EMPAL, and the 4 income categories in DRAM. Population and employment growth rates were randomly sampled from a bivariate normal distribution, assuming a correlation of 0.5 between the two growth rates. All model parameters were varied via random sampling from multivariate normal distributions resulting from maximum likelihood calibration, recognizing the correlation
observed during estimation. In all, 100 different input combinations, or scenarios, were modeled.

As with UrbanSim, outputs of both the land use and the travel demand model were considered for analysis. Outputs of the land use model considered for analysis were the average zonal residential density (Res. Dens.) and employment density (Emp. Dens.), weighted by the number of households and jobs in the zone respectively. Outputs of the travel demand model considered for analysis were the same as those used in the analysis of UrbanSim, i.e., the vehicle miles traveled (VMT), the vehicle hours traveled (VHT), and flows on the three links considered in the previous analysis.

The results indicate that contrary to a strong belief that socioeconomic inputs are more critical than any other model input, uncertain population and employment growth rates may not be the most significant source of uncertainty in ITLUP’s outputs. Population totals do affect the total flow observed on the links, but do not determine where this flow takes place. Because the travel model employed in the current study was origin-constrained, employment totals affect only the relative attractiveness of different zones, not the total trips produced. Nor do these growth rates significantly impact the (weighted) average residential and employment densities, which appear to be more sensitive to the spatial distribution of households and jobs. It is stressed that these results may be a manifestation of quirks in the model used for the study, and do not necessarily reflect actual urban behavior.

The evolution of uncertainty in ITLUP’s outputs is depicted in Figure 2. Uncertainty in model outputs appears to go up for every year the model is run, since, unlike UrbanSim, ITLUP does not explicitly incorporate density constraints or land use restrictions in its framework. Because the model tends to allocate jobs to large rural zones, which are located on the periphery of the region and are not served by any major links, its predictions of VHT and VMT are usually biased upwards. Interestingly, aggregate outputs of the travel demand model (i.e., VHT and VMT) appear far more variable than outputs of the land use model. This suggests that they are possibly more sensitive to the spatial distribution of households and jobs than aggregate outputs of the land use model.

![Figure 1. Evolution of Uncertainty in UrbanSim’s Outputs](image-url)
3 CONCLUSION

This study confirms some of the results of previous studies (Harvey and Deakin, 1995; Zhao and Kockelman, 2001), and suggests a few new results. For instance, not only may uncertainty in model parameter estimates may be a significant source of uncertainty in some model outputs, in some cases it may actually be a greater source of uncertainty than errors in socioeconomic projections. This is particularly so for outputs which are greatly affected by spatial distribution of households and/or jobs in the region and their spatial distribution. However, the validity of these results is constrained by the appropriateness of UrbanSim and ITLUP as integrated land use-transportation models.

Because land use-transportation models are usually used to forecast urban conditions several years in the future, it is important to understand how uncertainty in forecasts evolves over time. However, the level of uncertainty in the outputs of the two models considered appeared to follow strongly contrasting trends. In UrbanSim, the level of uncertainty in model outputs appeared to come down in later years, as the urban system being modeled approached saturation. For ITLUP, in the absence of density constraints and land use restrictions, the level of uncertainty in model outputs went up dramatically in later years, particularly so for outputs of the travel demand model. It is not clear, however, whether the results of the study are valid for all land use-transportation models in general, or whether they are a reflection of the shortcomings of UrbanSim and ITLUP in particular. It is also hard to differentiate between results that are generic to all land use-transportation models and those that are specific to the models considered in the study, or to the Eugene-Springfield data set.

Future work using UrbanSim should consider other inputs that were not varied in the current application, of which several are listed in previous sections. It should also consider a realistic correlation between inputs. While a well-distributed range of inputs is important, in order to obtain a clear sense of the distribution of outputs, the scope of any such work is limited by the time required to complete each simulation run. Future work with ITLUP might best focus on certain key parameters, in order to get a better sense of their effects.
Alternatively, it should include enough model runs to remove the effect of correlation in some of the model inputs, which confounded the results of the current study.

In order to generalize the results of the study to all land use-transportation models, it is necessary to consider other models such as MEPLAN or TRANUS, which take a different approach to land use-transportation modeling. Several data sets should be used in order to differentiate between results that are specific to a region, and results that are applicable to all land use-transportation models. And further microsimulation of individual urban actors behavior would be helpful for comparing the magnitudes of errors in predictions that may result.

Despite the caveats mentioned above, a general conclusion can be drawn from the study, which is deemed relevant to many land use-transportation models. When making projections regarding growth in a region’s population, predicting the spatial distribution of the population may be as important as or more important than predicting the regional totals. In contrast, predicting the regional total of employment may not be as critical, since what matters is not the total employment in the region, but rather its relative distribution. Also, a critical review of the structure of the model being used to forecast land use is necessary.

REFERENCES

Harvey, G. and Deakin, E. 1995. Description of the STEP Analysis Package, Berkeley, California.


