LAND USE ALLOCATION MODELING IN UNI-CENTRIC AND MULTI-CENTRIC REGIONS

Paper Presented at the 1994 TRB national conference

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Presented at the 75th Anniversary Annual Meeting of the Transportation Research Board. Washington, DC: January 1996.

ABSTRACT

Linking land use allocation models with transportation models was first accomplished in the 1970s. There has been an increase in the number of applications over the past several years as region planners have intensified their planning efforts to cope with new demands from ISTEA and from their local constituents. Planners in many other regions are questioning whether a land use allocation model would help in their planning activities. Some questions involve application of the models, given the increasingly multi-centric nature of our urban regions.

We have developed land use allocation models for three regions: Chittenden County (Burlington) Vermont, the four-county Tampa Bay region in Florida, and the three-county seacoast region of New Hampshire and Maine. These three areas represent three different regional forms. Burlington is a traditional uni-centric urban area. Tampa is a multi-centric regional center. The New Hampshire/Maine Seacoast region is a slice of the Eastern seaboard megalopolis, but is dwarfed by Boston to the south.

We have successfully applied the same basic land use allocation model to all three areas. The model can be used in uni-centric regions. It is especially helpful in multi-centric regions where in-fill is significant. With care paid to external conditions, the model can be successfully applied to urban subregions such as the New Hampshire/Maine Seacoast region. A simplified version of the model has also been integrated within GIS-based, linked land use, air quality and transportation planning model developed at Sandia National Laboratories.

The estimated models have been used to evaluate the effects of highway, transit, TDM, and land use policy alternatives. The transit alternatives evaluated include: bus, light rail, and commuter rail. The TDM alternatives include: preferential parking, parking fees, and gas taxes. The land use policies include local and regional growth centers.

INTRODUCTION

We have successfully integrated land use allocation models with transportation planning models in two regions, and are in the process of completing a third implementation.[1] [2] We have recently extended the first completed model to a wider geographic region. These land use allocation models serve two interrelated purposes:

1) to calculate land use scenarios that are realistic, internally consistent, and can be easily updated; and
2) to calculate land use scenarios that are realistically influenced by transportation measures including highway improvements, transit improvements, transportation demand management (TDM) strategies, and land use policy decisions.

Land use forecasts are traditionally developed by land use planners in a bottom-up approach. Future land use is assigned manually to each transportation analysis zone (TAZ). Delphi methods are also used where the thinking of a group of experts are combined, with iteration until consensus is reached. Within this paper, all methods not using a set of calculation rules will be called “manual.”

Several problems are inherent in manual methods. First, the process is very time consuming when applied to a fine zone structure. Second, it is difficult to achieve consistency in forecasts. Generally, different individuals have primary responsibility for different subareas. These individuals have different perspectives and different goals and assign growth differently. Third, the sum of the bottom-up TAZ forecasts may be unrealistic at the regional level. For example, there is often a mismatch between future projected jobs and future housing. Fourth, there is no simple way to update the forecasts in response to changing conditions.

Manual land use forecasts do not include consideration of important feedback forces between land use and transportation. Critics of traditional transportation planning have highlighted these deficiencies. The new requirements of the Intermodal Surface Transportation Efficiency act of 1991 (ISTEA) and the Clean Air Act Amendments of 1990 are focusing increased attention to these interrelationships.

Land use allocation models can address all of these deficiencies. After development, scenario analyses and updated forecasts can be generated quickly. These forecasts will be internally consistent. They will be balanced regionally. They will include the effects of transportation improvements and land use policy.

Are land use allocation models appropriate for all regions? This is a question that has many dimensions including economic and political considerations. Some of the more substantive issues involve the increasingly multi-centric nature of our urban regions. It has been argued that the best regions for application of land use allocation models are traditional isolated uni-centric regions.

> Given the issue of external effects, it would seem that the ideal location for implementation of a land use allocation model would be a relatively isolated urban area such as Portland, Oregon, or Columbus, Ohio. Such an area would not only have few external impacts, but would also be capable of providing more accurate regional control forecasts.[3]

We agree that land use forecasting is more complex in multi-centric regions than in uni-centric regions. However, there is greater complexity whether manual methods are used or whether a land use allocation model is used.

In any type of analysis, it is generally the case that complexity causes greater difficulties in manual methods than in computer methods. Land use forecasting is no exception. The regional control totals problem is identical in both cases, but the multi-centric effects problem can be much better addressed in a computer model than using manual methods. Human beings do a good job of visualizing a small number of relationships, and a fair job of forecasting based on them. They are unable to consider the implications of thousands of interactions among factors acting over a long period of time.

Land use forecasts are required for long-term transportation analyses. If existing models fall short of desired capability of modeling in multi-centric regions, then improved models are needed. This paper describes a model that was developed for allocating land use in multi-centric regions and the application of this model.

OVERVIEW OF THE MODEL

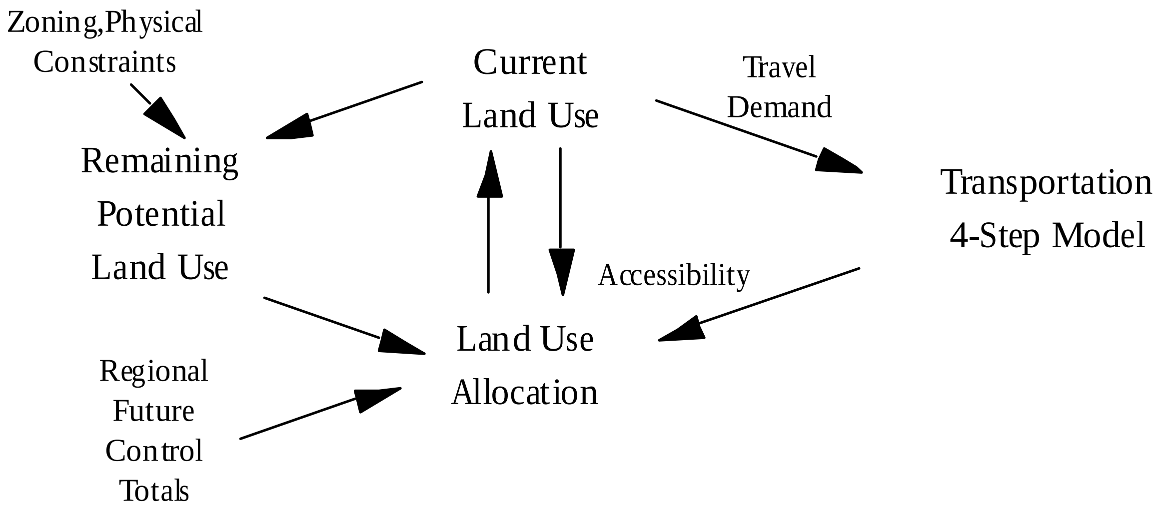
There is a large literature describing computerized land use allocation models. A wide range of models are described, some of which have not yet been applied completely to real urban areas. A review of land use allocation models with a focus towards application to growth areas has been done by Berechman and Small.[4] Another review was conducted by Cambridge Systematics and Hague Consulting Group for the Making the Land Use Transportation Air Quality Connection (LUTRAQ) project sponsored by 1000 Friends of Oregon.[5] Land use allocation models have also been discussed in recent transportation modeling guides to "best practices."[6 7]

Operational land use allocation models were first developed by Lowry in the 1960s.[8] In a Lowry-type model, basic employment is considered the fundamental engine of growth. Putman integrated land use allocation models and transportation planning models.[9] Putman-type models have been applied in a number of large metropolitan areas.[10] Some of these efforts include significant extensions to the basic model. For example, two major extensions made by the Puget Sound Council of Governments are 1) inclusion of a generalized accessibility variable to all employment and household locations in the region, and 2) use of a composite multi-modal cost impedance measure, rather than automobile travel time.[11]

We have updated the Lowry/Putman model structure to better represent suburban growth areas in the 1990s. Instead of designating employment as "primary" and "secondary," it is categorized as using typical transportation modeling categories such as "retail", "commercial", or "industrial." Instead of housing location being determined by the workplace of the "primary worker," locational choice is based on the generalized accessibility to all destinations. Generalized accessibility is calculated using a nested logit formulation[12], so that land use allocation incorporates transit accessibility. The effects of regulation on land use development are explicitly incorporated into the model structure.

An overview of the land use allocation model is presented in Figure 1. The incremental change in regional future control totals is allocated to the transportation analysis zone (TAZ) level based on current land use, the remaining potential land use, and accessibility.

Figure 1 — Overview of Land Use Allocation Model



The development potential is based on both physical and regulatory constraints. In all three projects, development potential was calculated at the TAZ level with the assistance of geographical information systems (GIS) software. A typical process would be as follows:

1) overlay TAZ by zoning district (zoning can be modified for alternative future scenarios)
2) overlay result by existing land use coverage
3) overlay result by sewage coverage
4) overlay result by soils (and slopes) coverage
5) overlay result by protected land layer
6) calculate development potential for each resulting polygon
7) sum development potential for TAZ

In all three implementations, we have emphasized consistency between the accessibility formulation used in the land use allocation model and the accessibility formulation used in the transportation model. In two of the implementations, the same estimated nested logit equation was used within the distribution, mode split, and land use allocation models. In the third implementation, composite impedance matrices are calculated within the transportation model and used directly in the land use allocation model.

The model equations are vary slightly among the implementations. A representative set of equations is described below.

The composite utility function U_{nmij} for land use type n in zone i as a function of land use type m in zone j is a function of an estimated coefficient α and the mode specific utility functions. Equation 1 shows the functional form for a nested logit case.

Equation 1: Composite Utility Function — nested logit function

$$U_{\text{nmij}} = e^{\left(\alpha \ln\left(e^{\theta \ln\left(e^{\text{Vauto}} + e^{\text{Vcarpool}}\right)} + e^{\text{Vbus}} + e^{\text{Vwalk}}\right)\right)}$$

An accessibility function, A_{nmi}, is a function of the existing land use of type m in zone j (L_{mj}), and the composite utility function U_{nmij}. This relationship is shown as Equation 2.

Equation 2: Accessibility Function

$$A_{\text{nmi}} = \sum_{mj} (L_{mj} * U_{nmij})$$

The generalized accessibility G_{n} for land use type n is a function of the weight parameters w_{nm} and the paired accessibility functions A_{nm}, summed over all land use types m as shown in Equation 3.

Equation 2: Generalized Accessibility Function

$$G_{\text{n}} = w_{\text{nResidential}} * A_{\text{nResidential}} + w_{\text{nRetail}} * A_{\text{nRetail}} + w_{\text{nNonretail}} * A_{\text{nNonretail}}$$

Allocation is done proportionally to the product of generalized accessibility and remaining potential land use.

Estimation of land use allocation model parameters was based on the historical changes in activity patterns. One of the greatest challenges in developing these models has been to develop accurate historical data with the same geographical breakdown as the current year data.

Model validation activities have included:

- comparing model output to history over the estimation period,
- review of model output by local experts, and
- sensitivity tests.

An important test of a model is whether it is able to reproduce historical behavior. It is an especially strong test when the validation data set is different from the estimation data set. Unfortunately, it has not always been possible to construct independent data sets. Therefore, the other two other validation efforts are important. Presenting draft future forecasts to local planners for review helps all parties to gain confidence in the model and its outputs, and can help uncover data errors.

Sensitivity analyses are also useful. The results of one of these sensitivity analyses is presented here. In order to test the importance of feedback from the land use allocation model on future transportation demand, sensitivity analyses were conducted using the Burlington Vermont regional model. The Burlington regional model with its "five-step" structure includes feedback through land use allocation, trip generation, trip distribution, and mode split. Feedback through trip distribution is especially significant. It models behavior which adjusts the pairing of origins and destinations in response to changes in transportation service levels. For example, if a new road makes traveling to a particular shopping center much faster, it will be more likely that this trip will be made.

These scenario analyses involved tests with a proposed commuter rail project and the proposed Circumferential Highway. The proposed commuter rail project is a modest single line system running 13 miles from the Burlington CBD to the south paralleling the Shelburne Road/Route 7 corridor. It would run on existing track. The frequency would be two per hour during peak periods.

Service was assumed to be implemented in 1998 and ridership for the year 2013 was forecast both with feedback and without feedback. Forecast ridership is modest in both cases but is two percent higher in the case with feedback This result is reasonable for this scenario. The increase in accessibility of a single rail line is limited, and automobile access and mobility is very high in the suburban area served.

The proposed Circumferential Highway is a limited access partial beltway to the northeast of the City of Burlington. It would provide a bypass to the urban section of I-89 and congested arterials, and provide improved radial access to suburban growth areas.

This highway was implemented in the model in 2003 and traffic volumes were forecast with and without model feedback. Segment volumes with feedback were 10 - 30 percent higher than without feedback, with an average of about 20 percent. There was considerable variation among segments, but about 80 percent of the difference was due to trip distribution feedback with the remaining 20 percent due to land use allocation.

The results again appear reasonable. The land use allocation impact of 20 percent of the average change due to feedback (20 percent) or about four percent of traffic volumes is significant but fairly small. This result was obtained after 10 years of land use effects and would be expected to grow larger over time. The trip distribution effect of 16 percent (80 percent of 20 percent) is very significant and also appears plausible. Trip distribution feedback is included in many urban models, and should be included in all urban models.

APPLICATION OF THE LAND USE ALLOCATION MODEL

We have integrated land use allocation models with transportation planning models in Chittenden County (Burlington) Vermont and the three-county seacoast region of New Hampshire and Maine. Implementation of a land use allocation model in the four-county Tampa Bay region is underway. Below, each project is described including the context for the work, the form of the implementation, and project results. The model was originally developed for application to multi-centric regions. The Burlington work is presented first because it is the least complex.

BURLINGTON VERMONT REGION

In the Burlington, Vermont region, the Chittenden County Regional Planning Commission/Chittenden County MPO decided to make major model improvements as a basis for its long-term planning work. In particular there was a strong interest in transit and in the relationship between land use and travel demand.

A "five-step" integrated model was implemented with feedback throughout the modeling chain. Development constraints data were developed using the regional planning commission's GIS data and capabilities. Land use allocation model parameters were estimated based on historical data over the period 1980 - 1993.

An interesting feature of this project was the combination of both predictive and normative land use modeling. Here, "normative" is used to describe modeling what would happen if a desired result could be achieved. In this case, the implementation of the regional plan was performed outside of the model, and differed substantially from both current experience and future predictive model forecasts. This type of modeling is currently being done within many urban areas in order to evaluative the transportation implications of alternative land use scenarios. Once a desirable future is found, the predictive model can come back into play and address the important question of how this future might be reached. What combination of policies such as zoning, transit investment, tolls, and so forth might work?

The two land use futures tested in this project were:

- maintenance of existing local zoning (year 2013 Local Zoning), and
- implementation of the regional plan emphasizing the role of growth centers at the regional, subregional, and local levels(year 2013 Regional Plan).

Alternative transportation futures were also defined. The purpose of these was to fully represent fundamentally different approaches rather than to define actual possible courses of future action. Three alternatives were examined:

1) a "maintenance only" future incorporating no new improvements but maintaining the existing system ("maintenance");
2) an SOV/highway-based future depending on expansions of highway capacity. These included capacity expansions to existing arterial routes and completion of a proposed circumferential highway for the region ("> highway"); and,
3) a transit-based system, utilizing the existing highway network but with dramatically expanded transit service ("> transit").

These transportation changes were coded into the network and combined with the land use alternatives to yield six basic alternatives for analysis.

The results of these analyses are illustrated in Tables 1 - 3 below.[13]

Table 1 — Land Use Allocation Summary for Alternative Scenarios

Land Use Regulation	Transportation System	% New Development in Regional Growth Centers	% New Development in Sub-Regional Growth Centers	% New Develop. in Local Growth Centers & Outlying Areas
1993 Base	Existing	27.5%	25.8%	46.8%
	Maintenance	11.4%	24.9%	63.8%
2013 Local	>Highway	11.3%	25.1%	63.6%
Zoning	>Transit	11.9%	25.9%	62.2%
	Maintenance	30.6%	45.4%	24.0%
2013 Reg.	>Highway	28.0%	44.2%	27.7%
Zoning	>Transit	28.6%	44.0%	27.4%

Table 2 — Regional Mode Shares for Alternative Scenarios

Land Use Regulation	Transportation System	Person Trips	Single Occupancy	Car Pool	Walk/ Bike	Transit
1993 Base	Existing	72,962	70.6%	26.3%	2.5%	0.6%
	Maintenance	95,111	70.8%	26.6%	2.2%	0.5%
2013 Local	>Highway	95,109	70.6%	26.7%	2.2%	0.5%
Zoning	>Transit	95,116	67.3%	24.9%	2.0%	5.8%
	Maintenance	95,262	70.3%	26.8%	2.3%	0.6%
2013 Reg.	>Highway	94,509	70.5%	26.6%	2.3%	0.6%
Zoning	>Transit	94,513	66.9%	24.9%	2.1%	6.0%

Table 3 — Vehicle Miles of Travel (VMT) Summary for Alternative Scenarios

Land Use Regulation	Transportation System	Peak Hour VMT	VMT/Person Trip
1993 Base	Existing	413,484	5.67
	Maintenance	561,597	5.90
2013 Local	>Highway	574,293	6.04
Zoning	>Transit	544,468	5.72
	Maintenance	541,190	5.68
2013 Reg.	>Highway	555,430	5.88
Zoning	>Transit	524,433	5.55

The regional transportation plan has been developed based on these general scenario results and analyses of specific potential projects. The model is now being used for studies of proposed light rail and commuter rail projects.

NEW HAMPSHIRE/MAINE SEACOAST REGION

The Pease/Seacoast MPO Transportation Model was developed following the closure of the Pease Air Force Base, and its planned re-development. The re-development plan was opposed by a consortium of environmental groups concerned with growth impacts, especially on air quality. These groups sued to block the development plans, and also to make invalid the transfer of land to the state of New Hampshire. The two municipalities where the re-development was planned also expressed concerns.

The state of New Hampshire worked to respond to these issues by developing a comprehensive transportation and air quality study. A regional model was developed as the foundation for these analyses. The Technical Advisory Committee for the project included The Pease Development Authority, the New Hampshire Department of Transportation, and staff from the three regional planning commissions (one in Maine) that comprise the Seacoast MPO. The land use allocation model was proposed to these clients as an option. This option was enthusiastically supported by the regional planning commissions who saw this as an expedient way to develop internally consistent land use forecasts that were responsive to the re-development plans.

The model was implemented as a menu-driven "five-step" model that sequences modules, manages files, and also produces air quality analyses. Development constraints were developed based on the state of New Hampshire's GIS system. Parameters were estimated based on observed land use changes over the period 1980 - 1990.

The model, including feedback from the land use allocation model, was used for all scenarios. Many scenarios were tested including various land use, highway improvement, transportation improvement, and TDM scenarios. An example scenario incorporating all components is:

- 2011 full development at Pease,
- widening Spaulding Turnpike, Route 1, Route 101,
- increased bus service area and service frequency, and
- greatly increased parking costs.

The model results passed the plausibility test of local and regional planners. The re-development activity was and remains very controversial. There was some questioning of forecast traffic volumes, but there was general acceptance of the land use forecasts.

The model proved particularly useful for forecasting growth in in-fill areas between established centers. The modeled area contains several small urban areas. The strongest growth is being experienced in areas that lie between these older centers. While trend extrapolation is incapable of forecasting these effects, the land use allocation model appears to do this fairly well.

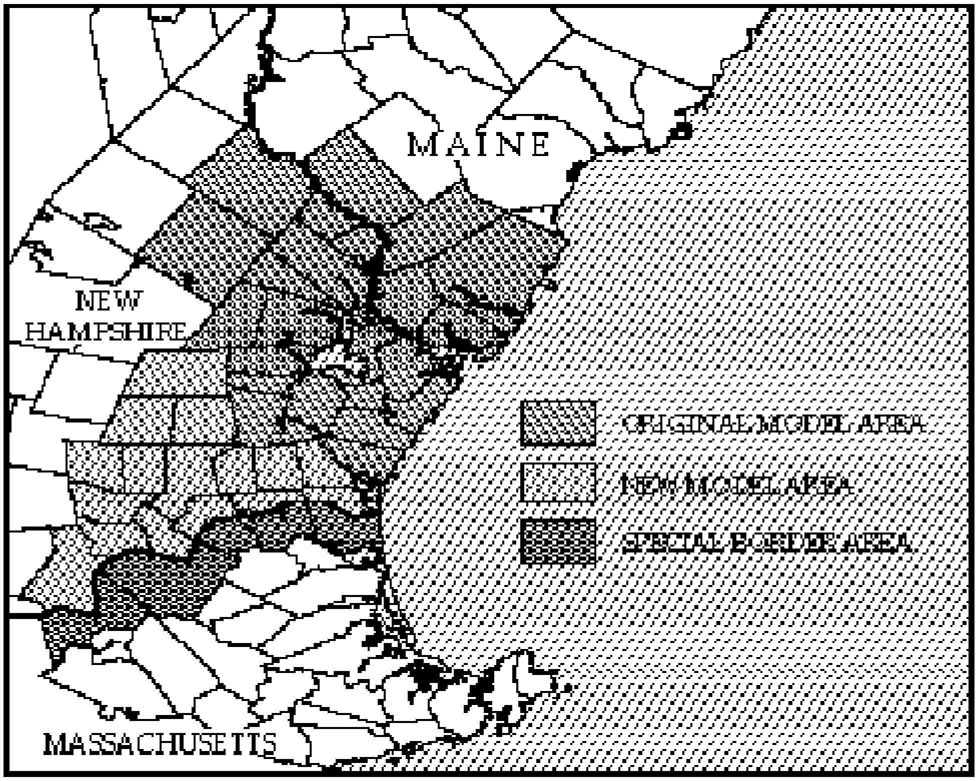
The model, completed in 1993, has recently been extended to a much wider geographic region. Figure 2 illustrates the original model boundary, the new area, and a special area of aggregated zones representing neighboring municipalities in Massachusetts. A major challenge in this project was how to manage the external boundary problem with Massachusetts. The border area is urbanized on both sides of the border. Full inclusion of a portion of Massachusetts was impractical, both because of funding issues and also that there is no good place to draw the line. If some of the border municipalities were included, the external boundary would then lie closer to Boston and create new difficulties.

The approach taken was to partially include the border communities in the model set. These municipalities were modeled as large aggregate zones for the purpose of trip generation and trip distribution. The distribution model was validated against auto intercept data collected at the state border.

For the land use model, the Massachusetts zones were treated as external and land use forecasts developed by Massachusetts planners were used for future conditions. Because an identical impedance model is used in distribution, mode split, and land use allocation, the "mass" in "Massachusetts" does affect land use allocation in the model.

The scope of this follow-on project did not permit a new validation effort for the land use allocation model. Instead, the original estimated and validated model parameters were used. Results appear reasonable, but it would be very desirable to test this approach in a full model development project, including parameter estimation.

Figure 2 — Expansion of the Seacoast Model



TAMPA BAY REGION

The Tampa Bay Region project involves an area with a much larger population than the other two projects, about 2 million population. The immediate client is the Florida Department of Transportation, but each of the four counties and the City of Tampa are also important constituencies for the work. The work is part of a major model improvement activity where four separate urban models have been merged into a single model by the prime contractor, Gannett Fleming.

The incorporation of a land use allocation model was specified in the RFP for the model improvement program. The Tampa Bay region has grown explosively. Much of the growth has been in-fill growth, for example between Tampa and St. Petersburg, or else suburban growth. Highway improvements aimed at satisfying this growth have appeared to lead to additional growth pressures. These forces are at work everywhere, but operate at a greater speed in Florida than in most urban areas.

The Florida DOT sees a need for integrated planning, but this integration is difficult to achieve. The three regional planning commissions in the New Hampshire/Maine Seacoast project saw the land use allocation model to be an advantage because they had not developed detailed land use forecasts of their own. In contrast, the planning staffs in the Tampa Bay region are more hesitant. Development of independent land use forecasts has been and continues to be a significant activity within these planning organizations.

In order to satisfy the needs of the local and regional planners, additional features have been implemented. These features include the ability to set control totals and minimum or maximum growth or percent growth by county, by superzone, and by TAZ. This results in greater control over the allocation and alleviates many of the planners' concerns. This feature is also useful for large regions where a single set of control totals may be inappropriate.

In this project, we were constrained to working with the standard Florida Standard Urban Transportation Modeling System (FSUTMS) which uses TRANPLAN. The land use allocation model has been implemented as a separate executable program on the IBM RISC machines used for the model. Composite impedance files are passed in TRANPLAN format to the land use allocation model. The land use allocation model returns updated land use files.

The land use allocation model software has been completed and tested. The base year transportation model has recently been completed. Work still to be completed includes finishing compilation of historical data, estimating parameters, and validating the model.

CONCLUSIONS

The land use allocation models have achieved the model purposes. They are a practical method of generating land use forecasts that are internally consistent and that can be easily updated. They also generate land use forecasts that are sensitive to the full range of policies that are of interest today: highway improvements, transit improvements, transportation demand management, congestion pricing, and land use regulation.

The land use allocation models have also passed the plausibility test. Both base case and scenario forecasts have been acceptable to local and regional planners.

The models are useful for traditional uni-centric urban areas but are especially useful for multi-centric areas where suburban in-fill is difficult to forecast using traditional methods. The models can also be extended to areas where external boundary effects are very important.

The land use allocation models described are "predictive", they attempt to forecast the future. These models can also be used effectively with "normative" modeling where the consequences of an idealized land use future are played out. In this case the role of the predictive land use allocation model is to look for a set of transportation and land use policies that will achieve the idealized future.

RECOMMENDATIONS FOR FURTHER WORK

We believe that current land use allocations are superior to manual methods. However, these models could be much better yet. Areas where further work is needed include: follow-up studies comparing land use forecasts to actual land use changes (for both manual and model forecasts), model application in regions bordered by urban areas, and research into land use allocation models for larger regions. There is also a need for easier to use models and better model interfaces.

As a first step in addressing this last need, we incorporated a simplified version of the land use allocation model into the Land Use, Air Quality, and Transportation Integrated Modeling Environment (LATIME), developed at Sandia national laboratories.[14] [15] LATIME represents an integrated approach to computer modeling and simulation of land use allocation, travel demand, and mobile source emissions for the Albuquerque, New Mexico, area. This environment provides predictive capability combined with a graphical and geographical interface.

The ultimate vision is for a suite of modules that operate together in a "Plug and Play" environment. The quest for this environment is currently frustrated by inconsistencies between file formats and operating environments, but these obstacles are gradually diminishing with advances in computer software.

REFERENCES

[1]Marshall, N. L. and S. J. C. Lawe. Forecasting Land Use Changes for Transportation Alternatives. Presented at 5th National Conference on Transportation Planning Methods, Seattle, WA: April 1995.
[2]Marshall, N. L. and S. J. C. Lawe. Land Use Allocation Models for Multi-County Urban and Suburban Areas. *4th National Conference on Transportation Planning Methods: A Compendium of Papers Based on A Conference Held in Daytona Beach, Florida, May 1993*. Washington, DC: September 1993.
[3]Cambridge Systematics, Inc. with Barton Aschman Associates. *Short-Term Travel Model Improvements, Final Report* (DOT-T-95-05). Prepared for Federal Highway Administration, Washington, DC: October 1994.
[4]Berechman, J and K A Small. Modeling land use and transportation: an interpretive review for growth areas. *Environment and Planning A*, 1988, 20: 1285-1309.
[5]Cambridge Systematics, Inc. with Hague Consulting Group. Making the Land Use/Transportation/Air Quality Connection: Modeling Practices, Volume 1, prepared for 1000 Friends of Oregon, October 1991.
[6]Harvey, G. and E. Deakin. *A Manual of Regional Transportation Modeling Practice*. Washington, DC: National Association of Regional Councils, July 1993.
[7]Cambridge Systematics, Inc. with Barton Aschman Associates. Short-Term Travel Model Improvements. Prepared for U.S. Department of Transportation and U.S. Environmental Protection Agency (DOT-T-95–05), October 1994.
[8]Lowry, I. S., 1964. *A Model of Metropolis,* RM-4035-RC. Santa Monica, CA: The Rand Corporation.
[9]Putman, S H. *Integrated Urban Models: Policy Analysis of Transportation and Land Use*. London, England: Pion Ltd, 1983.
[10]Putman, Stephen H. Transportation and Land Use: Defining the Links: Notes on Organizing Structure and Some Comments on Integrated Methods of Analysis. Presented at Linking Transportation and Land Use Planning: A Key to Suburban Growth Management, New York: NY, December 1990, sponsored by the Lincoln Institute of Land Policy.
[11]Watterson, W.T. Adapting and Applying Existing Models: DRAM and EMPAL in the Seattle Region. *Journal of the Urban and Regional Information Systems Association*, Fall 1990.
[12]Ben-Akiva, M., and S. R. Lerman. 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand*. Cambridge, MA and London: MIT Press: 276-322.
[13]These results are a subset of those presented and discussed in greater detail in Lawe, S., R. Chamberlin, M. Oman and J. Segale. "An Integrated Transportation/Land Use Model for the Chittenden County, Vermont MPO." Presented at the 1995 Transportation Research Board Annual Meeting, Washington, DC: January 1995.
[14]Hanley, Charles J., C. Blewett, M. Lewis, and N. Marshall, 1995. "The Land Use, Air Quality, and Transportation Integrated Modeling Environment." Transportation Research Board 5th National Conference on Transportation Planning Methods Applications, Seattle, WA.

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[15]Hanley, M. Lewis, Charles J., C. Blewett, L.A. Barbour and N. Marshall, 1995. "The Land Use, Air Quality, and Transportation Integrated Modeling Environment." 33rd Urban and Regional Information Systems Association (URISA) Conference. San Antonio, TX: July 1995.