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EVALUATION OF MODELING TOOLS FOR ASSESSING LAND USE POLICIES AND STRATEGIES

Prepared for

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EXECUTIVE SUMMARY

BACKGROUND

The rapid increase in vehicle miles traveled in the last 50 years (and the resulting increase in emissions from transportation sources) has accompanied land use development patterns that rely on the automobile as the primary means of transportation. EPA is required by the Clean Air Act (CAA) to provide assistance to state and local governments in meeting National Ambient Air Quality Standards (NAAQS). The purpose of this document is to provide such assistance in the form of an assessment of the current state of integrated transportation and land use modeling, i.e., modeling systems used to project future patterns of both travel demand activities and land use activities.

SUMMARY

One of the objectives of this study is to assess the ability of currently available land use models and integrated land use-transportation models to evaluate the impact of land use policies and strategies designed to reduce travel demand. The identified land use strategies included:

- high density development at various spatial scales
- mixed use development at various spatial scales
- infrastructure modifications

The impact of each of these strategies on travel demand can be evaluated with an appropriate travel demand model, which includes adequate representation of all the travel modes of interest and how they are selected by travelers.

Three types of policies were identified for encouraging higher density and mixed land use:

- zoning;
- non-monetary incentives; and
- monetary incentives

Three modeling systems that incorporate algorithms to project the spatial distribution of land use activities, and that are generally commercially available to planning agencies, were identified:

- DRAM/EMPAL, part of ITLUP
- MEPLAN
- TRANUS

A significant potential limitation for all of these models, with respect to their ability to evaluate the impact of the land use strategies of high density and mixed use on travel demand is the size of analysis zones. Zones are usually significantly larger than census tracts, due primarily to two factors: (1) availability of input data, especially with respect to place of employment; and (2) difficulty in achieving successful calibration with a disaggregated configuration. Because the scale of development of many of the proposed strategies is significantly smaller, they would be difficult to detect in a large zone application. The TRANUS model can be configured with nested zones, so that spatial resolution is finer in targeted areas, but even the nested zones are typically the size of several census tracts.

Zoning The impact of zoning policies on development decisions cannot be well-represented in DRAM/EMPAL. MEPLAN and TRANUS, in contrast, include floor space zoning restrictions in the spatial choice formulation, as well as development costs. The former could represent development density at the zonal level. Specified development costs presumably could be modified in accordance with density regulations to influence development decisions. However, because these parameters can be specified only at the zonal level, the size of zones may limit the ability of these models to evaluate policies designed to influence development at small spatial scales, e.g., near a transit stop.

Similarly, zoning policies that encourage mixed development might be represented in MEPLAN and TRANUS by manipulation of floor space zoning maxima for various activities among zones. However, because the model formulation treats new development for the various activities independently, the extent to which land uses mix at the micro-scale level (i.e., smaller than zones) cannot be addressed.

Monetary Incentives Because DRAM/EMPAL has no direct representation of costs in employment or residential location decisions, monetary incentives to guide land use development cannot be represented. In MEPLAN and TRANUS development of new floor space is projected, in part, on the basis of development costs. Therefore, policies that offer monetary incentives to developers to build in targeted zones or at specified minimum densities could be represented in the models in terms of decreased development costs. Again, these can only be specified at the zonal level, so that the size of the zones is an important consideration for evaluating policies that target small scale development characteristics.

Non-monetary incentives/disincentives Some non-monetary incentives, such as reduced parking requirements or accelerated permit processing, are designed to lower costs for developers, so that responses would be similar to those for monetary incentives, which cannot be represented in the DRAM/EMPAL models, but can be represented in the MEPLAN and TRANUS models.

For all three models, an incentive such as an infrastructure upgrade that resulted in reduced travel impedance, suitably estimated with a travel demand model, could be represented in the models and influence locational choice. Similarly, parking restrictions can be represented as increased travel impedance within the models. However, the spatial scale of application of these policies may be significantly smaller than the scale of the analysis zones, so that detection of any impact would be difficult.

For all the models, the limited number of independent variables used to make projections may lead to underestimates of the full impact of some infrastructure improvements, such as mixed development or pedestrian-friendly environment attracting additional households to an area. All the formulations consider composite travel impedance (time and out-of pocket costs) and past patterns of residential location choice. In addition MEPLAN and TRANUS consider costs of floor space. However, an increase in the attractiveness of a zone due to addition of special features will not be captured by any of the models without reformulation of the fundamental algorithm of the models.

RECOMMENDATIONS

The following improvements to standard land use and transportation modeling tools would facilitate their use in evaluating the impact of the strategies and policies.

- Development of data and procedures to allow land use analysis at fine spatial resolutions, such as census tracts;

- Development of data to determine the relationship between special land use features of interest (e.g., pedestrian-friendly environments, mixed land use development), and neighborhood attractiveness;

- Development of data and procedures to allow incorporation of pedestrian and bicycle modes, as well as public transit, into travel demand models;

- Development of data to determine the relationship between mixed use development and travel mode selection;

- Development of data and procedures to allow incorporation of trip chaining into travel demand models;

- Development of data and procedures to allow incorporation of temporal choice into travel demand models.

1 BACKGROUND

The combustion of fossil fuels by the transportation sector is estimated to contribute nearly a third of emissions of CO_2, a greenhouse gas, in the United States (US DOE, 1996). It is also a major contributor to a number of criteria pollutants, such as NO_2, CO, ozone, and particulate matter. The rapid increase in vehicle miles traveled in the last 50 years (and the resulting increase in emissions from transportation sources) has accompanied land use development patterns that rely on the automobile as the primary means of transportation. The Environmental Protection Agency's (EPA) role in controlling air emissions extends from criteria pollutants at the regional and local scale, to greenhouse gases at the national scale. EPA is required by the Clean Air Act (CAA) to provide assistance to state and local governments in meeting National Ambient Air Quality Standards (NAAQS). The purpose of this document is to provide such assistance in the form of an assessment of the current state of integrated transportation and land use modeling. These models can potentially be used to evaluate the impact of proposed land use-related measures (e.g., zoning restrictions), which may influence transportation volumes, and consequently mobile source emissions and air quality. In addition, such models may potentially improve the accuracy of evaluations of the impact of transportation-related measures, by providing a more realistic representation of the linkages between land use and travel demand.

This document is intended to help policy makers at all levels understand how transportation and land use models may improve policy development and implementation. First, a brief discussion of land use strategies and their relationship to vehicle miles traveled (VMT) reduction is presented in Chapter 2, followed by an overview of the travel demand and land use modeling tools in Chapter 3. Next, the current land use and transportation modeling practices of several US metropolitan planning agencies are reviewed in Chapter 4. Chapter 5 contains a detailed summary of the most widely used land use and integrated land use-transportation models, including an assessment of each selected model's effectiveness in capturing impacts of land use measures on land use and traffic outcomes. The findings are summarized in Chapter 6.

2 LAND USE STRATEGIES AND POLICIES FOR VMT REDUCTION

This discussion focuses on land use strategies and land use policies. It is important to distinguish between the two. Land use strategies aim to improve aspects of the urban environment and are the desirable outcomes of land use policies. For example, a land use strategy of increased density of development in a particular area may be encouraged with a land use policy, such as zoning regulations setting minimum density levels. This distinction is important because land use strategies, (e.g., high density of development), are the direct inputs to the travel demand model, so that a land use model is not required for evaluation. Land use policies (e.g., zoning restrictions), on the other hand, require evaluation in order to estimate the impact on the spatial distribution of development. Such evaluations may be accomplished with a land use model.

The California Air Research Board (CARB) recently sponsored a study to identify land use strategies that can be implemented to improve the efficiency and facilitate the use of transit, pedestrian, and other alternatives to single-occupant motor vehicles (Dagang and Parker 1995; Parker 1996). The study consisted of an intensive literature review to locate and summarize the findings of studies with modeled or empirical data to quantify the impacts of such strategies on the transportation system. The results of this review were combined with input from a project advisory committee to select nine transportation related land use strategies, and to recommend a set of implementation policies. A summary of these strategies is provided below.

Land Use Strategies

The nine strategies identified in the CARB study are:

1. <u>Concentrated activity centers</u> Encourage pedestrian and transit travel by creating "nodes" of high density mixed development, that can be more easily linked by a transit network.

2. <u>Strong downtowns</u> Encourage pedestrian and transit travel by making the central business district a special kind of concentrated activity center, that can be the focal point for a regional transit system.

3. <u>Mixed use development</u> Encourage pedestrian and transit travel by locating a variety of compatible land uses within walking distance of each other.

4. <u>Infill and densification</u> Encourage pedestrian and transit travel by locating new development in already developed areas, so that activities are closer together.

5. <u>Increased density near transit stations</u> Encourage transit travel by increasing development density within walking distance (0.25 to 0.50 miles) of high capacity transit stations, and incorporate direct pedestrian access.

6. <u>Increased density near transit corridors</u> Encourage transit travel by increasing development density within walking distance (0.25 to 0.50 miles) of a high capacity transit corridor.

7. <u>Pedestrian and bicycle facilities</u> Encourage pedestrian and bicycle travel by increasing sidewalks, paths, crosswalks, protection from fast vehicular traffic, pedestrian-activated traffic signals, and shading.

8. Interconnected street network Encourage pedestrian and bicycle travel by providing more direct routes between locations. Also, alleviate traffic congestion by providing multiple routes between origins and destinations.

9. Strategic parking facilities Encourage non-automobile modes of transit by limiting the parking supply, and encourage carpooling by reserving parking close to buildings for carpools and vanpools.

The first six strategies recommend increasing the density of development at various spatial scales, and mixing land uses so that a variety of activities will be close together. Since government agencies cannot accomplish these goals directly, land use policies are required. These policies may be evaluated with a land use model. CARB's recommendations for such policies will be discussed below.

The issue of scale is important in the evaluation of land use strategies and policies. Both land use models and transportation models formulate the modeling areas as a set of contiguous zones. The spatial resolution of the zones is limited primarily by the resolution of available data. Some land use models rely on economic data (e.g., employment by sector) to forecast the changes in land use activities. Travel demand models, on the other hand, rely primarily on demographic and transportation network data, which are typically available at finer resolution than economic data. Limited spatial resolution implies that current land use models might not be able to specify changes in land use activities at scales sufficient to detect, for example, increased density within 0.25 to 0.50 miles of a transit station, or transit corridor (Strategies 5 and 6). Depending on the size of high density "nodes" (Strategy 1), land use models may also have difficulty in identifying them as outcomes. Moreover, if separate land use and travel demand models are linked for analysis, there may be a mismatch between the zone definitions of the two models.

If pedestrian and bicycle facilities (strategy 7) and interconnected street networks (strategy 8) are accomplished directly by a government agency, they may be thought of as land use policies that may influence land use patterns by changing accessibility. In addition, because these two strategies involve direct modifications of transportation networks, they may also directly impact travel demand patterns. The influence of the modified accessibility on travel demand may be evaluated directly with a travel demand model that includes walk and/or bicycle mode choices. Alternatively, these strategies may be implemented for new development through regulations or incentives, discussed below. Again, the scale of such projects may be an important determinant of the ability of land use models to capture their impacts.

Some parking restrictions (strategy 9) may similarly be accomplished directly by government agencies and so may be considered land use policies. Others would have to be implemented indirectly through regulations or incentives for private property parking.

Land use policies

The CARB study recommended a number of land use policies to implement the identified strategies. These policies fall into one of three categories: zoning and other types of regulations; non-monetary incentives; and monetary incentives. The following list of policies is derived from those suggested by the study:

I. Encourage focused higher density by

A. allowing transfer of unused development density capacity in outlying areas to permit development density above maximum limits near central areas and transit (zoning/regulations and non-monetary incentives);
B. allowing increased density for residential, retail, and employment generating uses in central areas and around transit (zoning/regulations and non-monetary incentives);
C. setting minimum densities for residential, retail, and employment generating uses in central areas and around transit (zoning/regulations);
D. requiring no net decrease in residential density for redevelopment (zoning/regulations);
E. stating densities in terms of square feet of land per dwelling unit, rather than minimum lot size, to encourage clustering (zoning/regulations);
F. granting incentives (e.g., reduced parking requirements, accelerated permit processing, infrastructure upgrades) for development that focuses on existing urban areas and infill (non-monetary incentives);
G. adjusting development impact fee structures or giving tax breaks to encourage infill and increased density development near transit and activity centers, and to discourage outlying development (monetary incentives).

II. Encourage mixed-use zones by

A. Allowing mixed use, which is now prohibited in many places (zoning/regulations);
B. requiring mixed uses, with certain percentages of residential, public, and commercial uses in target areas (zoning/regulations);
C. using fine-grained zoning to achieve mixed use while insuring residential zones are buffered from heavy industrial zones with light industrial and commercial zones (zoning/regulations);
D. using mixed-use overlay zoning, to add a second use to an area that is primarily in another use, e.g., commercial corridors along major arterials in a primarily residential area (zoning/regulations);
E. granting incentives (e.g., reduced parking requirements, accelerated permit processing, infrastructure upgrades) for development that locates transit- or pedestrian-oriented amenities, like housing or child care near commercial uses and pedestrian-oriented design (non-monetary incentives);
F. adjusting development impact fee structures or giving tax breaks to encourage mixed use (monetary incentives).

III. Encourage pedestrian, bicycle, transit, and carpooling activity by

A. requiring connected, narrower streets with trees and sidewalks in new development (zoning/regulations);
B. requiring bicycle lanes and transit stops on larger streets in new development (zoning/regulations);
C. requiring traffic-calming devices in new development, e.g., textured paving at crossings, frequent intersections with pedestrian-activated traffic signals, and

traffic circles (zoning/regulations);

D. reducing requirements for setbacks and minimum lot sizes to create a stronger connection between buildings and sidewalks (zoning/regulations and non-monetary incentives);

E. requiring pedestrian scale signs in pedestrian and transit-oriented areas (zoning/regulations);

F. reducing minimum parking requirements near transit hubs and for projects providing features that encourage pedestrian, bicycle, and transit activity (zoning/regulations and non-monetary incentives);

G. setting parking maximums in transit- and pedestrian-oriented areas (zoning/regulations);

H. requiring preferential parking for carpools (zoning/regulations).

3 OVERVIEW OF MODELING TOOLS[1]

Why Use Models?

Why use computer modeling tools to make land use and transportation projections? Many metropolitan planning organizations (MPOs) use expert judgment for land use forecasting; however, most use modeling tools for transportation projections. According to SANDAG (1995):

> "Forecasting traffic volumes in response to land use changes is probably the most commonly requested model application. Proposed land use changes can be quite detailed, such as a site-specific project that a developer may need analyzed as part of an environmental impact report. At the other extreme are generalized regionwide growth alternatives."

There are a number of advantages in using computer models rather than expert judgment to make projections. In large, or even moderate-size, metropolitan areas, a land use plan is likely to combine a wide range of policy options. Computer models can process the multitude of data items that comprise the relevant parameters and variables of the land use and/or transportation system. The model formulation is an explicit specification of system interactions, and the results indicate which interactions are the most important in any particular situation. In addition, model results often highlight the nonintuitive consequences of the combined policies that might otherwise be overlooked.

Computer models can also be used in conjunction with expert judgment. For example, in the past the Southern California Association of Governments has used DRAM/EMPAL in conjunction with projections made by local planning agencies in order to highlight any inconsistencies. The modeling results could then be used as a basis for reconciling varying judgments of local planners.

According to Tomas de la Barra, who developed the TRANUS model, an integrated land use-transportation modeling system can also be a useful alternative to construction of origin-destination matrices from large-scale survey data. He suggests that data from a much smaller survey can be used to calibrate an integrated model, which will then estimate the needed matrices.

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[1] It is important to note that the land use modeling tools discussed herein will not make planning decisions, but can be used to evaluate the consequences of planning decisions. There are some models in use that attempt to select the optimum configuration according to some criterion, such as minimizing transportation costs and activity costs. Examples are TOPAZ (Oryani, 1987) and models by Boyce (1986, 1990). However, according to Harris (1996):

> "Efforts at network optimization have proved intractable in spite of numerous efforts. Some efforts have partially succeeded in using a heuristic (or approximate) model of network optimization to produce effective marginal improvements to networks, but have failed to solve the larger problem of generating a good or optimal network from scratch...It is now known that these difficulties stem from the structure of the overall network and land-use problems, which have multiple local optima, on which improvement methods 'hang up', with no possibility of further progress."

Inputs, Outputs, and Potential Linkages

It is a well-accepted principle that land use configuration influences travel patterns. Characteristics such as density of employment or population at a particular location, affect both the number of trips that originate from that location, and the number of trips for which that location is a destination. This is the primary land use/transportation linkage captured by current travel demand models. In addition, the spatial distribution of demographic characteristics, also specified in the land use system, can influence the use of transportation modes, e.g., private vehicles or public transit. By the same token, transportation planning decisions have been shown to influence land use. For example, the construction of a new freeway, or the elimination of congestion on an existing route, changes the accessibility of land on that route, hence the value of the land, and hence the uses which the land market assigns to it. As noted by Sicko and Watterson (1991), land use planners have seen that transportation facilities have had a more profound and permanent impact on urban form than land-use plans.

The similarity in the aim of land-use and transportation modeling traditions leads to close theoretical connections, despite the fact that they evolved relatively independently of one another. Transportation and urban travel demand models were developed in the field of traffic engineering, and institutionalized in the large urban transportation studies of the 1950s and 1960s. Most land use models in operation today were derived from the Lowrey model, developed in the field of urban planning in the late 1950s. These models have not been as widely used as transportation models (Sicko and Watterson, 1991). However, the assumed linkages between land use and transportation have resulted in increasing the use of the combination land use and transportation models, applied together as part of the planning process.

Figure 1 shows the general relationships between these models. Both models divide the modeling domain into a set of analysis zones. The land use model represents the relationships between the supply of physical space in each zone (e.g., land, floor space) and activity demands for that space (e.g., employment, households, shopping). One of the factors influencing the demand is accessibility between zones, typically defined in terms of either travel time or a combination of travel time and out-of-pocket costs (i.e., travel impedance). The travel times may be estimated with a transportation, or travel demand model. The outputs of land use models are estimates of the spatial distribution of the demand activities among zones.

The transportation, or travel demand model, similarly represents the relationships between the supply of transportation infrastructure and equipment (e.g., roadway links, public transit supply) and the travel demands for them. One of the factors influencing the demand for travel to and from each zone is the distribution of activities among the zones. The current activity distribution should be derived from actual data, but future projections may be estimated with a land use model.

Typically analyses which use these two types of models in concert have been conducted using "one-way" linkages. For example, to estimate future travel demand, a study may utilize a land use model to project the future spatial distribution of origins and destinations as output, and then use those locations as inputs to a travel demand model. Travel demand patterns are generally assumed to respond quickly to land use changes, while the land use activity patterns are assumed to respond slowly to accessibility changes. If land use patterns are not a policy variable

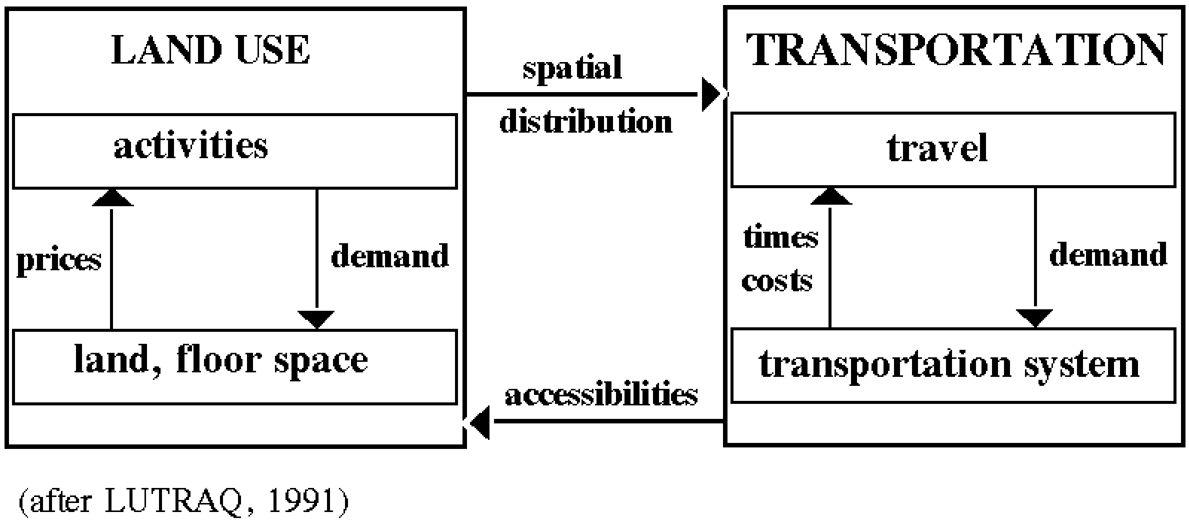

Figure 1. Potential linkages between land use and transportation systems in land use and travel demand models.

(i.e., the policy measures are not land use-related), and if they are presumed to change only slightly during the time frame of the transportation investment decision (i.e., minimum influence of changes in accessibility on land use patterns), then it is reasonable to model future land uses independently of transportation system changes. However, if significant changes in land use activity patterns measures or the length of the time frame, a richer modeling of the interaction between land use and transportation becomes necessary.

Starting in the 1980's more attention was paid to "two-way" linkages in evaluating policies, where land use influences travel demand and travel demand influences land use. All of the land use models discussed in this document include travel impedance (i.e., time and/or cost of traveling between zones) as an important variable, if not the only variable, influencing locational choice. The impedance is typically derived from outputs of the standard travel demand model (thus, the "two-way" linkage, as illustrated in Figure 1).

There are other ways in which land use factors are recognized as affecting travel patterns, but these are not yet explicitly integrated into typical travel demand models. For example, the existence of inter-modal connections (i.e. Park and Ride), or the prevalence of sidewalks and bicycle lanes, can affect mode choice. Because of the long lag times between changes in travel demand patterns and subsequent changes in land use activity patterns, and because of the complexity of both systems, consistent relationships have been difficult to discern from observation. Southworth (1995) notes that in trying to analyze the impact of the transportation system on land use:

> "[W]e are dealing with both a large number and a wide variety of activity types, decision makers, and underlying motives for action. While urban residents have chosen in growing numbers to move outward from city centers in search of more space at lower rents, most commercial and industrial users still seek the economies of scale associated with spatial proximity to similar and complementary employment activities. With the

onset of the information society, a third important trend is the emergence of locationally indifferent service and information based companies which are no longer tied to the location of key resource inputs or local markets for their products. We therefore have at least three very different types of locational activity operating within our urban areas."

The degree to which these different types of locational activities are represented in land use models is an important characteristic to determine in assessing these models.

Travel Demand Models

Historically, regional transportation models were designed to predict urban transportation needs and network designs. The models were originally developed in the 1950's and were usually used to estimate travel demand along specific transportation corridors (e.g., freeways) or for different modes of travel (e.g., transit). Their use for air quality analysis was not widely recognized until the last decade, when state transportation agencies began to use the models' activity estimates to estimate regional motor vehicle emissions. Several different transportation modeling software packages (e.g., TRANPLAN, EMME/2, MINUTP) are available, most developed as PC or workstation versions (with enhancements) of the Federal Highway Administration's Urban Transportation Planning System (UTPS) model.

The traditional travel demand model, such as UTPS, first divides the urban area into traffic zones, from which trips originate (trip production), and to which trips are destined (trip attraction). The models are typically formulated into four estimation steps, illustrated in Figure 2, (Urban Analysis Group, 1990):

1. <u>Trip generation</u> - The trip generation step utilizes a series of models in which zone-based information about employment and population is used to estimate the extent to which each zone is an origin and/or destination for trips. These projections can be disaggregated, depending upon data availability, to identify sub-sets of employment and population types with different travel behavior. Estimates can also be made separately according to the purpose of trip, e.g., home-to-work, home-to-other, or other-to-other.

2. <u>Trip distribution</u> - The trip distribution steps links the trip origins and destinations for each type of trip through a gravity, or spatial interaction model, in which the demand for travel between any two points is positively correlated with the number of trip origins and destinations for the zone pair, and negatively correlated with the impedance between the two zones. The results are commonly called "trip tables". Typically travel time is used as a measure of impedance or accessibility. The gravity type of formulation is the same as that at the core of the Lowrey land use model, from which all the land use models discussed herein are derived.

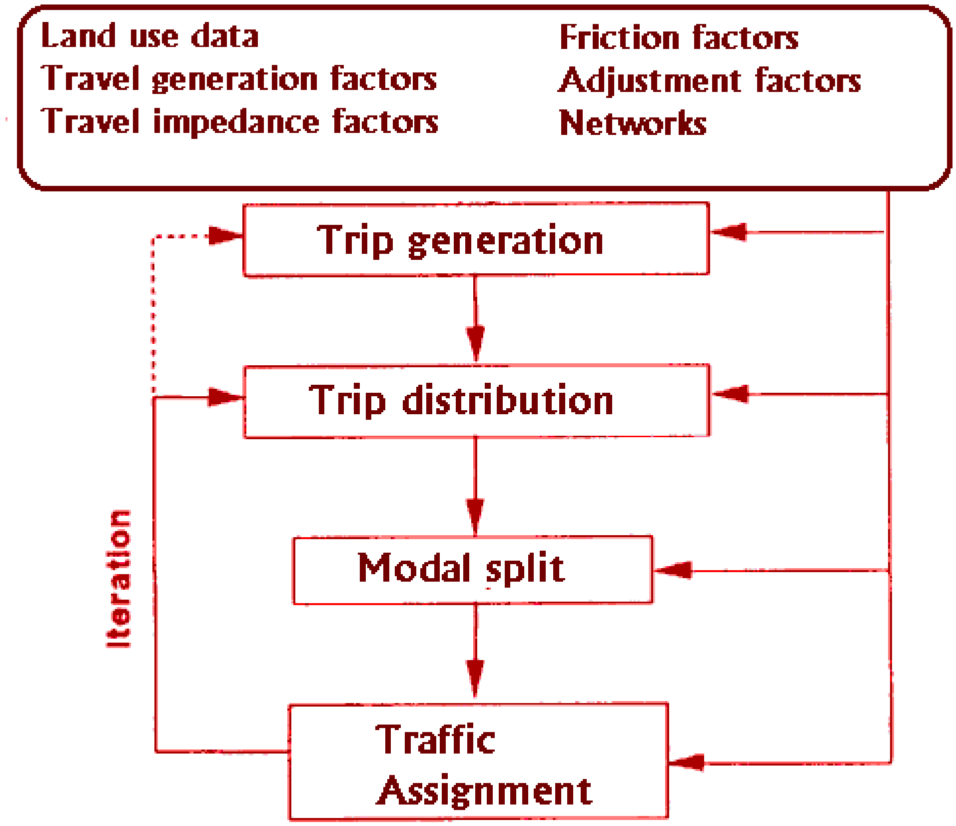

Figure 2. Overview of the traditional four-step travel demand model.

3. Modal choice - The mode choice step disaggregates trips between the highway and other modes. Mode choice models may include such factors as demographic group, cost, relative travel times, and trip purpose.

4. Trip assignment - The assignment, or loading, of vehicle trips to specific links in the highway network and person trips to links in the transit network occurs in this step. The assignment algorithm is usually based on the assumption that people try to minimize travel time. There are several different approaches that can be used to determine the traffic assignment that results in the smallest travel times. For example, the model may repetitively assign a user-selected percentage of trips incrementally along the network paths that result in the minimum travel time. As certain links fill up with traffic, the speeds on them are reduced and travel time increases, until other links become more attractive. The process continues until all trips are assigned.

Typical travel demand models are data intensive. The basic types of input data required are as follows:

Land use data The trip generation step requires information about the socioeconomic characteristics of each traffic analysis zone. This may include, for example, population, households, employees, or schools. Any type of land use or economic characteristic that can be quantitatively related to the number of trips produced or attracted may be included. Some of this land use information, e.g., population income levels, may also be used in the modal choice step.

Trip generation factors The trip generation step also requires information about the number of trips associated with each socioeconomic characteristic of a traffic analysis zone, e.g., the number of trips per household in a given income category. The factors can be determined based on local surveys or, if data are lacking, standard technical guidance documents such as are published by the Institute of Transportation Engineers (ITE).

Travel impedance factors The trip distribution step and the modal choice step require information about the impedance, or difficulty, of trips between each pair of zones. Impedance factors are usually expressed as either time, distance, or cost, and are based upon local surveys.

Friction factors The trip distribution step also requires information about the relative impact of a unit of impedance on the likelihood of trips between each pair of zones. These "friction factors" may differ according to the purpose of the trip. For example, drivers are more likely to choose to travel long distances or pay tolls for trips to work rather than trips to buy milk.

Adjustment factors The mathematical relationships used in the trip distribution step often include an adjustment factor which modelers apply to make predicted travel distribution match common sense expectations or observed behavior, i.e., the adjustment factors are used to calibrate the model. These factors are sometimes retained in future year forecasts of travel activity.

Highway network The trip assignment step requires an abstract description of the highway network as nodes and links. A node typically is assigned to a specific physical point in the region, such as an intersection or a transit stop where a transfer can be made. Links define roadway segments between nodes and have associated speed, distance, capacity, and other attributes.

Transit network The trip assignment step also requires an abstract description of the transit network. It includes the links a specific route travels and the nodes where stops are made.

The four stages of a travel demand model may include feedback at different stages. For example, the speeds calculated in the trip assignment step, which incorporate the slowing caused by traffic congestion on each link, may be fed back into the trip distribution and mode choice steps. Using the congested speeds, the model again determines the split of travel among available modes (e.g., drive-alone, transit) and then determines the most reasonable path in the network travel would take. The iterations continue until either all paths connecting a pair of zones have the same travel time so there is no advantage in switching paths, or until a predetermined number of iterations has been made.

The use of feedback is almost always limited to the last three of the four stages described above, even when the model is used to predict future travel activity. Planning agencies generally do not feed the information on travel choices and ease of travel between zones produced by the four stage model back into either the trip generation step or the modeling of future land use patterns.

Transportation model outputs include vehicle volumes by link on the highway network, person trips on the transit network, congested speeds by link, trip origins and destinations and intrazonal trips by zone. These predictions can represent average daily or peak/off-peak period travel.

Note that different types of information are important for projecting vehicle emissions of different pollutants. For example, CO_2 and NO_x emissions generally correlate well with total distance driven, regardless of the number of trips over which that distance is distributed. CO and HC emissions, however, are significantly influenced by the number of trips, in addition to the distance, since these pollutants have enhanced emissions when vehicles are started with a cold engine (i.e., cold starts; EPA, 1993). This distinction is important to keep in mind when developing and evaluating strategies for reducing mobile source emissions. For example, a strategy of concentrated activity centers, designed to encourage travel to a central location where the functions of otherwise multiple vehicle trips can be combined, may reduce emissions of some pollutants even if VMT is unchanged.

Note also that timing of emissions may be an important consideration for ozone precursors NO_x and HC. For example, the California's South Coast Air Quality Management Plan tested the hypothesis that future ozone exceedances may occur more often on weekends, despite lower stationary source emissions, due to the temporal pattern of motor vehicle emissions: a build up to a plateau level sustained throughout much of the day on weekends, rather than peak emissions in morning and evening rush hour on weekdays (South Coast Air Quality Management District, 1996). They concluded that further work is required to fully quantify the weekend ozone episode phenomenon.

Limitations of Travel Demand Models

The standard travel demand models currently in use have a number of limitations which affect their ability to evaluate land use policies. Those discussed in the following section include:

- lack of feedback of travel impedance to trip generation;
- omission of trip chaining behavior;
- omission of temporal choice behavior;
- omission of non-motorized travel modes; and
- insufficient attention to urban freight

<u>Feedback of travel impedance to trip generation</u>

The lack of feedback of projected traffic congestion to the trip generation step means that the model cannot capture the impact of traffic congestion on decisions about whether a trip occurs. That is, the number of projected trips depends only on the land use variables (i.e., population and employment) and the fixed trip generation factors (e.g., the number of home-to-other trips per household in income range A), no matter how congested or uncongested traffic becomes; traffic generation is formulated as inelastic with respect to such travel cost changes. Changes in impedance only affect projections of the route and mode of the trips, even though one would expect that congestion would have an impact on people's trip-making behavior.

According to Southworth (1995), empirical efforts to assess the relationship between travel impedance and trip generation have been unsuccessful. He suggests that this may be because cross-sectional, single day trip sampling focuses only on short-term travel decision behavior. The travel impedance effect may be more consistently operable in the longer-term, where transportation costs may be traded off against other household costs (e.g., housing location), in ways that affect trip frequency. Therefore, the feedback of traffic congestion on trip generation may be most appropriately modeled indirectly, through its impact on residential location decisions in the land use model or land use portion of the integrated model; i.e., by capturing the "two-way" linkages discussed above.

One goal of the land use policies discussed previously is to reduce VMT, which is likely to result in some congestion relief. In reality, such relief may result in an increase in the number of trips taken as a secondary effect, that would partially offset the primary VMT reductions. A similar increase in trips is commonly observed when a freeway is expanded to relieve congestion. This secondary effect is not captured by the standard travel demand model application, suggesting a tendency to overestimate VMT reductions associated with the land use policies.

Trip chaining

Another problem with the standard travel demand model, as well as the travel demand portions of most integrated land use-travel demand models, is the omission of trip chaining behavior, i.e., multipurpose, multi-stop daily travel chains. This omission means that the models are not capturing a significant characteristic of actual travel behavior, and thus introduce uncertainty into resulting trip and VMT projections. This omission is particularly serious for evaluation of land use policies, such as mixed use development, which are designed in part to encourage such trip chaining behavior by placing multiple destinations in close proximity (e.g., work and shopping). Inability of the models to treat trip chaining is likely to lead to underestimating the effectiveness of mixed use development on trip and VMT reductions.

Temporal choice

As noted previously, timing of emissions, and therefore travel, may be an important consideration for ozone air quality. Furthermore, timing of trips (e.g., peak or non-peak) affects travel impedance, and thus the magnitude of emissions. The standard travel demand model, as well as the travel demand portions of most integrated land use-travel demand models, do not include time of travel as a choice variable in the model formulation, but use a fixed temporal distribution for each type of trip. If mixed land use strategies combine work places with commercial shopping, some shopping trips that coincide with evening commuting may be shifted to midday or replaced by pedestrian trips, leading to some congestion relief and, thus, reduced emissions. However, this effect cannot be captured by models that use fixed temporal distributions for trips.

Alternative travel modes

The simplest applications of the standard travel demand model include only automobile travel, so there is no mode choice. When mode choice is included, typically only automobile and public transit travel modes are considered. More advanced applications may include alternative travel modes, such as pedestrian and bicycle modes, but these are often specified according to a fixed percentage of intrazonal travel. In these cases, the models will not capture the impacts of land use strategies designed to encourage pedestrian and/or bicycle travel modes, such as mixed use, pedestrian and bicycle facilities, and interconnected street networks. In order to assess such strategies, pedestrian and/or bicycle travel modes must be included as choice variables. Moreover, to assess the potential impact of pedestrian and bicycle facilities or interconnected street networks, the model formulation must include variables which can be used to represent the presence of such amenities. Although few operational travel demand models incorporate such features, an innovative modification of the standard model that does so is described below.

Urban freight

According to Southworth (1995), little research has been done to determine the relationships between management practices and either short-term scheduling of freight movement or long-term decisions about work place location with respect to customers and freight terminals. The efforts that have taken place consist of a series of largely independent studies, focused on very specific aspects of urban freight travel, that have not yet resulted in a conceptual framework for urban goods movement analysis.

The standard travel demand model typically addresses freight transport with an exogenous scaling factor. Thus, it will not capture the impact of strategies to increase the density or clustering of industrial facilities, in order to reduce intra-industry freight transport.

Furthermore, current changes in freight transport practices in some industries include a major shift away from warehousing to just-in-time parts and product deliveries, a change which may lead to significant increases in VMT. Thus, travel demand models calibrated to historical data, reflecting older practices, may underestimate current and future freight transport VMT.

Some of the economically-based integrated land use-transportation modeling systems, such as MEPLAN and TRANUS, can explicitly address freight movement, as well as passenger travel.

Potential Enhancements to Standard Travel Demand Models

This section presents examples of two enhanced travel demand models with features that address some of the issues discussed above.

LUTRAQ

The study *Making the Land Use Transportation Air Quality Connection* (LUTRAQ; Cambridge Systematics et. al., 1996) was a national demonstration project which targeted the Portland, Oregon metropolitan area. The goals of LUTRAQ were to (1) identify alternative land use development patterns that reduce travel demand and increase the use of alternative travel modes, and (2) develop transportation modeling procedures that forecast the travel behavior associated with those alternative land use patterns.

The study used Putman's DRAM/EMPAL land use planning system and the Portland Travel Forecasting Model. The Portland Travel Forecasting Model is one of the most advanced in operation, and it includes many enhancements to the standard travel demand model described above. For example, it contains an auto ownership submodel so that households are characterized by the number of automobiles owned in addition to other parameters. This parameter influences both the number of trips generated and the modal choice. The modal split process is divided into two parts, the first consisting of a split between walk/bike and auto/transit (pre-mode choice), and the second consisting of a split between auto and transit (mode choice) .

As part of the LUTRAQ study a number of modifications were made to the original version of the Portland Travel Forecasting Model, so that some of the strategies considered could be properly evaluated. The strategies of interest included development density, mixed use development, and a favorable pedestrian environment. Density was defined as the number of employees or residents within one mile of the zone. A Pedestrian Environment Factor (PEF) was also defined to reflect ease of street crossings, sidewalk continuity, local street characteristics (grid versus cul-de-sac), and topography. The submodels modified were those that were expected to be affected by these features: auto ownership, pre-mode choice, and mode choice. The modifications were implemented by re-estimating the predictive equations with additional parameters.

Results showed that development density and PEF improved the performance of the auto ownership, pre-mode choice, and mode choice submodels. The modifications were particularly effective in improving the ability to estimate the effects of development density and the pedestrian environment on pre-mode choice (walk/bike vs. auto/transit).

SANDAG

The San Diego Association of Governments (SANDAG) uses a tailored version of TRANPLAN for their travel demand forecasting. SANDAG has a 4,545 transportation zone system for most transportation modeling, with a more detailed set of 25,929 Master Geographic Reference Areas (MGRAs) used for transit access procedures and special applications.

The modal choice process includes six modes: drive alone, 2 person autos, 3 or more person autos, transit-walk, transit-auto, and other. The model determines mode shares (stratified by time period, income level, and trip type) based upon the level of service provided by each mode and trip maker characteristics.

The travel share captured by transit is specified to depend on the amount of activity within walking distance of a transit node. SANDAG assumes one-half mile is the maximum distance people will walk to transit. Auto access to transit is specified to depend on travel times and park-and-ride lot locations.

Land Use Models

Most operational urban land use models are derived, at least in part, from Lowrey's (1964) "Model of Metropolis" for the city of Pittsburgh. The approach developed by Lowrey links together two spatial interaction modules, shown as the two top boxes and the two bottom boxes in Figure 3. One allocates employment to a set of land use zones on the basis of employment levels in industries that export products from the area (i.e., manufacturing and primary industries). The employment forecasts come from outside the model, often from a regional economic model. The Lowrey model and those derived from it then project residential locations of the families of the employed workers on the basis of the employment locations, using a "gravity" type function. This is similar to the trip distribution step of the standard travel demand model, and uses a similar travel impedance variable.

A second spatial interaction module allocates employment in the service sector across zones on the basis of residential locations. The service sector employment generates a second set of families of employed workers to be allocated to residences. Residential and service locational processes are iterated until minimal additional employment is projected, i.e., an equilibrium is approximated. Estimates of either land area occupied or floor space used within each zone is

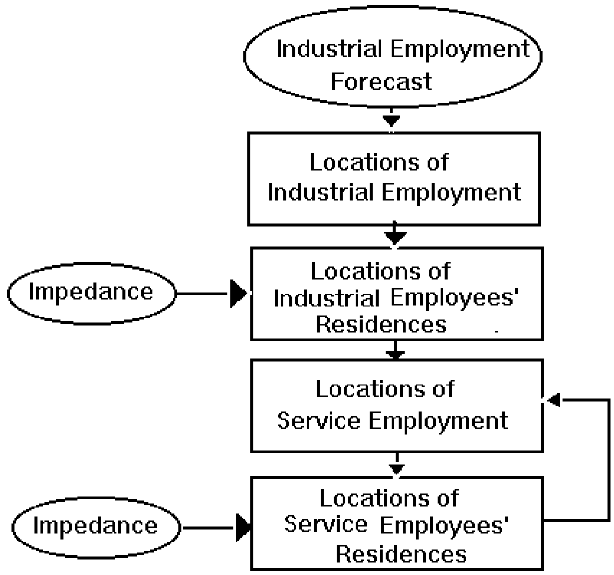

Figure 3. Overview of Lowrey-type land use model.

derived from residential and employment activity projections, combined with activity-to-floor space rates. Totals are constrained by physical limits and planning restrictions within a zone.

More recently some land use models, such as MEPLAN and TRANUS discussed below, have incorporated approaches developed by Wingo (1961) and Alonso (1964), to include the relative rent for land (comparative prices) in making allocations, as well as impedance. In these models, individuals select residential locations on the basis of a trade-off between housing price and transport time and cost. The process is represented in the model with of a "bid-rent function," which describes how much each household is willing to pay to live at each location. Each location is assumed to be rented to the highest bidder.

Land Use Model Limitations

Currently available land use models have a number of limitations that introduce uncertainty into the resulting projections. Some of these limitations are discussed in this section, such as

1. Representation of polycentric urban development, and
2. Non-transportation factors for business siting.

One of the major issues currently challenging the limits of existing land use models is changing urban development patterns. Traditional modeling approaches have assumed that growth spreads out from the center of a city, with a radial highway network focused on a centrally located CBD. However, many of urbanized areas conform to a more "polycentric" model. Suburban areas, traditionally considered to be primarily residential, are developing into employment and other types of activity centers, generating their own versions of CBD-like traffic-related problems.

As Southworth (1995) notes:

> "What is currently lacking in our operational models is any in-depth analysis of how such subcenters originate, develop, and perhaps eventually become smaller cities in their own right. Despite the long, active history of urban economic analysis, little light is shed on this process. Traffic congestion may be an important indicator of when a new industrial park of mixed use activity center is likely to be needed, but where these will be implemented, and which existing centers will continue to compete successfully, is much less obvious."

He notes that an important consideration in understanding this process is locationally-induced economies of scale on the site selections of industrial facilities, which may be influenced by interfirm communication, labor market economies, opportunities for specialization, and common intermediate inputs.

Evaluation of policies and strategies with modeling tools

As noted above, the objective of this document is to assess the capability of available land use and travel demand modeling tools to evaluate and quantify the impacts of proposed land use related measures on mobile source emissions. Conceptually this might be separated into two steps: (1) the impact of the land use policies on projected land use activities, and (2) the impact of the projected land use activities on travel demand.

The ability of a land-use model, or the land use portion of an integrated model, to evaluate the candidate land use policies will depend upon its ability to represent the policy within the parameters and input variables of the model. The ability of a land-use model to evaluate the policies *accurately* depends upon its capacity to correctly represent the impacts of the parameter/variable on land use activity. Model calibration is used to develop quantitative estimates of relationships between input and output variables. Model validation is used to evaluate the accuracy of the estimates.

Model Calibration

Calibration is a procedure used to develop estimates of the parameters of model equations which best fit the general model structure to a specific observed data set. The model parameters then represent an estimate of the relationship between input variables and model outcomes; that is, a representation of underlying behavior. Model calibration is typically the most resource intensive part of a modeling exercise.

Note that successful model calibration only indicates that the structure of the model includes the important variables that influence behavior (or correlate well with variables that influence behavior) under the conditions prevailing for the calibration data set. While the model is likely to accurately represent behavior under similar conditions, i.e., for small changes in input variables, model calibration does not ensure that the model to predict behavior under conditions that are quite different, such as those that might prevail if some of the proposed policies were implemented.

Model Validation

Model validation refers to a process of comparing model predictions to observed data that have not been used to calibrate the model. Such predictions may or may not represent conditions that are substantially different from those used to calibrate the model.

According to Wegener (1994), "remarkably few validation exercises are reported in the modeling literature". Notable exceptions are reported in Webster et al. (1988) for seven of the nine models participating in a model comparison exercise by the international study group on land use-transportation interaction (ISGLUTI); Prastacos (1986) for an application of the POLIS model; and Hunt (1994) for an application of MEPLAN to the city of Naples, Italy. Southworth (1995) notes that the major constraint in these exercises is the availability of data, particularly consistent data sets which span an amount of time necessary to capture the impact of important changes in infrastructure and land use. Hunt (1994) notes that it is often difficult to distinguish data problems from errors in a model's formulation or in its underlying assumptions. Thus, improved model validation will require improved procedures for collecting comprehensive data.

An alternative evaluation procedure, suggested by Cowing and McFadden (1984), is to assess model performance on the basis of realism in process. That is, the model should be judged on how well it represents how decision makers behave.

Policy evaluation issues

An implicit assumption motivating some of the proposed land use policies is that under certain circumstances people will change their behavior. The ability of a model to capture behavioral changes depends upon the inclusion of related variables in the model structure. Generally, such variables are absent, however, and the representation of behavior is limited to that observed in the past, or more specifically, in the calibration data set. For example, "jobs/housing balance", a type of mixed use development, is thought to lead to an increase in pedestrian and transit travel by locating employment and residential land uses within walking distance of each other. To the extent that the trips at issue are home-to-work trips, the impact of this strategy will be to affect at most the fraction of zone residents who are employees of local businesses.

In the standard travel demand model, the proportion of such residents projected in the trip distribution step is only marginally influenced by small changes in intra-zone travel times. This proportion will be primarily determined by the value in the calibration data set, i.e., the historical proportion, which is typically small. According to Putman (1991):

> "In point of fact, only a rather modest percentage of the new employees would actually be likely to live in the new housing. The model outputs would undoubtedly reflect this...Historically, at least in the last half of the twentieth century, the great majority of employees have not lived immediately adjacent to their place of work. The central element of the jobs/housing balance as a trip reducing strategy is the assumption that if employees could live adjacent to (or very near) their place-of-work, they would do so."

Cervero and Landis (1996), however, cite studies of commute distances and times in Seattle-Tacoma, Florida, and the San Francisco Bay Area that show lower values for residents of areas where jobs and housing units are more balanced. The Bay Area study also showed that workers in such areas more often use alternatives to the car. Lawrence (1994), in research comparing modal choice among census tracts, found that transit usage and walking increase as density and land-use mix increase. These findings suggest that a jobs/housing balance may indeed increase the attractiveness of the area for local employees compared to past attractiveness. That is, a mixed-use strategy may increase the proportion of residents who are employees of local businesses, in addition to influencing mode choice among such residents.

The underlying behavior captured by the standard travel models, however, reflects that observed in the past through the calibration data set. Significant changes in circumstances that might lead to changes in the attractiveness itself, such as the ability to walk to work, cannot generally be represented with currently available travel demand modeling tools.

Gravity type residential choice models have a similar limitation. A policy of simply allowing mixed land use, which would somewhat decrease intra-zone travel times and increase available land for development, would be unlikely to significantly increase the proportion of new residences projected to be located in the zone by such models. Again, this proportion will primarily be determined by the historical value specified in the calibration data set. Moreover, although a decrease in intra-zone travel time resulting from close proximity between work places and residences could influence some residential decisions, a problem of scale comes in here as well. The zones used in land use models are typically significantly larger than a mixed land development area. The intra-zone travel impedance value would, therefore, average together the reduced travel time/cost of the mixed use development area with the overall value for the zone. Thus, even the marginal impact that might otherwise be captured by the model is likely to be diluted due to problems of scale.

4 MPO USE OF MODELING TOOLS

Overview

Information about current land use and transportation modeling practices of twenty-five metropolitan planning organizations (MPOs) was compiled from a combination of published literature review, agency reports, and telephone interviews. A discussion of the findings from this data collection effort are provided here. Figure 4 shows the organizations from which information was collected.

Figure 4: Metropolitan Planning Organizations reviewed.

New York Metropolitan Transportation Council	Atlanta Regional Commission
Hampton Roads MPO (Norfolk-Virginia Beach)	Denver Regional COG
Southwest Pennsylvania Planning Commission	Northeast Illinois Planning Commission
Northeast Ohio Areawide Coordinating Agency	Ohio-Kentucky-Indiana Regional COG
Southeast Wisconsin Regional Planning Commission	Mid-Ohio Regional Planning Commission
New Orleans/Sidell Regional Planning Commission	North Central Texas COG
Wasatch Front Regional Council (Salt Lake-Ogden)	East-West Gateway Coordinating Council
Twin Cities Area Metropolitan Council	Houston-Galveston Area Council
Southern California Association of Governments	Sacramento Area COG
Association of Bay Area Governments (San Francisco)	San Diego Association of Governments
Portland-Vancouver Metropolitan Service District	Puget Sound Regional Council
Delaware Valley Regional Planning Commission	Orlando Urban Area MPO*
Tampa Bay MPO*	

*Only land use model information was available for this agency

Land Use Modeling

Table 1 shows the land use models used by each of the 25 organizations in this study. As shown in the table, 13 of them do not use a land use model at all, but rely exclusively on expert judgment to forecast future land use development. Of the other 12 areas, 8 use S.H. Putman's DRAM/EMPAL modeling package for their land use forecasting. None of the other software packages (i.e. POLIS, RSG) are utilized by more than one area in this study. Many agencies use in-house models in some capacity, either to prepare data for entry into a commercial model, as an all-in-one forecasting model, or in a sequence of models used in combination with other analysis tools and expert judgment to make forecasts. The San Diego Area Council of Governments uses EMPAL in combination with several in-house programs that replace the functions of DRAM. For some agencies, geographic information system (GIS) software is currently a very important part of their land use decision-making process. Many of the others report that GIS will soon become an integral part of their forecasting, but they are still in the process of developing and integrating their GIS system.

TABLE 1: Land Use Models Used by Metropolitan Planning Organizations

Area	Land Use Model: DRAM/EMPAL	POLIS	In-House	Other	None	Comment
Association of Bay Area Governments (San Francisco Bay Area)		✓				Also uses an in-house model of the regional economy
Atlanta Regional Commission	✓					
Delaware Valley Regional Planning Commission					✓	
Denver Regional COG			✓			A spreadsheet-based tool which allows them to look at policy variables is used
East-West Gateway Coordinating Council (St. Louis)					✓	
Hampton Roads MPO (Norfolk-Virginia Beach)					✓	
Houston-Galveston Area Council	✓					
Mid-Ohio Regional Planning Commission					✓	
New Orleans/Sidell Regional Planning Commission					✓	
New York Metropolitan Council					✓	
North Central Texas COG	✓					
Northeast Illinois Planning Commission	✓					
Northeast Ohio Coordinating Agency Policy Board					✓	
Ohio-Kentucky-Indiana Regional COG					✓	
Orlando Urban Area MPO	✓					
Portland-Vancouver Metropolitan Service District	✓					
Puget Sound Regional Council	✓					
Sacramento Area Council of Governments	✓					
San Diego Area Council of Governments				✓		Models used: PLUM, DEFM, EMPAL, SOAP
South West Pennsylvania Regional Planning Commission					✓	
Southeast Wisconsin Regional Planning Commission					✓	Agency tried to use a land use model in the late 1960's but was unsuccessful
Southern California Association of Governments					✓	Previously used DRAM/EMPAL
Tampa Bay MPO				✓		Using the Resource System Group (RSG) model, which follows closely the structure of DRAM/EMPAL
Twin Cities Area Metropolitan Council (Minneapolis-St. Paul)					✓	
Wasatch Front Regional Council (Salt Lake-Ogden)					✓	

Of those areas not using a land use model, many have considered using DRAM/EMPAL. The Denver Regional Council of Governments considered replacing their in-house model with DRAM/EMPAL but decided not to because of limitations in its ability to incorporate "policy variables" which the agency uses in its land use forecasting. Some areas like the Southern California Association of Governments (SCAG) reported using DRAM/EMPAL in the past but decided that a combination of in-house models, geographic information system (GIS)software and expert judgment was the most effective way for them to make land use projections.

All of the areas using DRAM/EMPAL had Putman and Associates, the developer of the software, assist in setting up the system. Each of them has set the modeling package up on a 486 or Pentium-class personal computer. Most reported that training and experience are necessary in order to run DRAM/EMPAL. Once trained, the agency staff are able to run the programs for the agency without the use of Putman's services. Some areas, like the Houston-Galveston Area Council, made the model easier to use by developing a simple user-interface.

At a minimum, land use models require employment, population and housing data as inputs. More sophisticated models may require additional inputs such as land use types and impedance factors for access to employment and open space. The agencies surveyed typically obtained this information from the US Census data, household surveys, or from local and regional government statistics.

Travel Demand Modeling

Travel demand models are one of the central transportation analysis tools used by all of the MPOs contacted for this study. Table 2 shows the type of travel demand model used by each of the 23 organizations for which data were collected. Nearly half (48%) of the 23 agencies use TRANPLAN to make travel forecasts. The second most frequently used model, MINUTP, is utilized by 23% of the agencies. Several agencies, including Association of Bay Area Governments (ABAG) and Puget Sound Regional Council (PSRC), have made, or are planning to make, a transition from the use of UTPS to a different commercially available package. Others like the North Central Texas Council of Governments (NCTCOG) have developed sophisticated in-house models. One of the noteworthy features of the NCTCOG model is the use of an elaborate mode choice element that includes light rail, HOV travel, peak and off-peak travel, levels of service, congestion delay and toll roads.

Few of the agencies using TRANPLAN have modified the model to incorporate modes in addition to vehicle and public transit. The Southeast Wisconsin Planning Commission is an exception, however, having successfully included walking and biking modes in their model. Nearly all the other agencies expressed similar plans to include these modes in the future. Not all attempts at introducing other modes have met with success, as in the case of the Ohio-Kentucky-Indiana Regional COG which tried to include an HOV mode choice but could not achieve an acceptable level of accuracy with the available data.

The data-intensive nature of travel demand models dictates that agencies collect several types of data for input. Most models require socioeconomic data (employment, population, housing), transit data, and road network links. The implementing agencies typically use household travel survey data to calibrate the model. NCTCOG has put together a special information collection and dissemination team exclusively for this purpose. The group has conducted numerous surveys to collect data on regional travel, employee travel, vehicle occupancy and parking patterns.

TABLE 2: Travel Demand Models Used by Metropolitan Planning Organizations

	Travel Demand Model							
Program	UTPS	TRANPLAN	MINUTP	EMME2	In-House	Other	None	Comments
Association of Bay Area Governments (San Francisco Bay Area)	✓							ABAG is currently making the transition to a MINUTP-based system
Atlanta Regional Commission		✓						
Delaware Valley Regional Planning Commission		✓						
Denver Regional COG			✓					
East-West Gateway Coordinating Council (St. Louis)			✓					
Hampton Roads MPO (Norfolk-Virginia Beach)			✓					
Houston-Galveston Area Council					✓			In-house model is based upon the UTPS model
Mid-Ohio Regional Planning Commission		✓						
New Orleans/Sidell Regional Planning Commission		✓						
New York Metropolitan Council		✓						
North Central Texas COG					✓			
Northeast Illinois Planning Commission							✓	
Northeast Ohio Coordinating Agency Policy Board		✓						
Ohio-Kentucky-Indiana Regional COG		✓						
Portland-Vancouver Metropolitan Service District		✓						
Puget Sound Regional Council				✓				PSRC changed from using UTPS plus in-house models to using EMME2 , 2 yrs ago
Sacramento Area Council of Governments			✓					
San Diego Area Council of Governments		✓						
South West Pennsylvania Regional Planning Commission			✓					
Southeast Wisconsin Regional Planning Commission		✓						
Southern California Association of Governments		✓						
Twin Cities Area Metropolitan Council (Minneapolis-St. Paul)		✓						
Wasatch Front Regional Council (Salt Lake-Ogden)			✓					

Other agencies rely on occasional household surveys to collect the necessary data for calibrating and running their model.

The types of policies evaluated by the agencies using land use and travel demand models include long range plan development, transportation improvement program analysis, corridor studies, air quality conformity analyses, major investment studies, and other special studies (i.e. sensitivity analyses, equity analyses). Most of the agencies have ongoing modeling development programs underway to improve the accuracy of the models and refine their forecasts. The Denver, Houston, and St. Louis agencies are all investigating ways to incorporate a feedback mechanism between their land use projection procedures and transportation models. Others, such as the Southern California Association of Governments reported that incorporating feedback between their modeling packages is, at the present time, still too difficult.

Case Studies Of Twelve Selected Agencies

Association Of Bay Area Governments (ABAG) of the San Francisco Bay Area

ABAG uses the Projective Optimization Land Use Information System (POLIS) to project land use, employment (6 sectors), housing (1 type), and population to 119 zones in the nine counties composing the San Francisco Bay Area. POLIS was first developed and applied to the Bay Area in 1983-84. POLIS is part of a modeling system used by ABAG. The other models are:

- The Regional Economic-Demographic Modeling System (REDS), which forecasts regional population and employment for 38 sectors;

- The County Employment Forecasting System (CEFS), which forecasts employment by county for 32 sectors; and

- The Subarea Projections Model, which allocates POLIS forecasts to census tracts.

REDS and CEFS provide control totals for POLIS. Travel cost is specified as a combination of travel time and out-of-pocket costs, so that the impact of improved transit service, higher tolls, or more expensive gasoline on residential location can be estimated.

POLIS can be run either with or without land use capacity constraints. This allows ABAG to perform sensitivity analyses to assess the impact of the transportation system levels-of-service on the reallocation of jobs and housing to more accessible areas, given the partial or total absence of local zoning controls. Sensitivity analyses such as these are not possible with other models, like DRAM/EMPAL, which lack the necessary land use constraints. Once completed, POLIS modeling results are used as inputs to the travel demand model, which is run by another agency, the Metropolitan Transportation Commission (MTC).

Transportation cost data, including level of service matrices, are provided to ABAG by MTC. MTC currently uses the UTPS travel demand model software, but is in the process of transferring to a MINUTP-based system. Their travel demand configuration includes 3 auto modes (drive alone, 2 passengers, 3 or more passengers) and transit, but uses the same travel cost calculation as POLIS. Input data are derived from the US Census and outputs of POLIS. Policies investigated by MTC include major investment studies, long range plans, air quality conformity analyses, and equity analyses.

Because the transportation modeling system is run by a different agency than the land use modeling system, feedback between the systems is limited to a biennial update by ABAG of their socio-economic forecast series and to special sensitivity studies needed by the MTC.

POLIS can be run on any 386/486 PC running DOS 5.0 or higher. It uses the 32-bit Lahey EM F77 compiler and the Phar Lap 386/DOS Extender. It requires approximately 4 megabytes of memory. Input and output files are in ASCII format.

ABAG reports that substantial training and expertise are needed to operate the POLIS modeling system, because a significant amount of expert judgment is included. Specialized training and expertise are also required for the travel demand model.

Portland, Oregon Metropolitan Region

The study *Making the Land Use Transportation Air Quality Connection* (LUTRAQ; Cambridge Systematics et. al., 1996) was a national demonstration project to develop methodologies for identifying alternative suburban land use patterns and evaluating their impacts. The target of study was the Portland, Oregon metropolitan area. The study used Putman's DRAM/EMPAL land use planning system and the Portland Travel Forecasting Model. The travel forecasting system, one of the most advanced in operation, is described above.

The LUTRAQ study encountered difficulties in calibrating the DRAM/EMPAL models for Portland when using a spatial resolution of 328 census tracts. The poor calibration results for Portland's employment allocations were attributed to inconsistencies between employment data sets for historical years. Similarly, the poor calibration results for residential allocations were attributed to inconsistencies between residential data sets for historical years, due to the splitting of census tracts. The low spatial variation in household data among census tracts was also cited as a factor.[2] It was noted that better goodness-of-fit and parameter estimates are made when the independent variables of the model are strongly correlated with the dependent variable, a condition that is difficult to detect if either variable shows little variation. The DRAM problem was addressed with a change in the formulation of the DRAM model, but a number of experiments failed to accomplish satisfactory calibration of EMPAL. It was noted that a coarser spatial resolution of 100 zones improved the calibration performance of both models significantly.

It was also noted that EMPAL had difficulty in representing Portland's legislatively defined Urban Growth Boundary, which prevents development beyond the urban fringe and results in a low percentage of vacant developable land in the Portland region. The result is that the percentages of developed land in each zone are relatively uniform, and that vacant land and the extent of development are not strongly correlated with new household location.

Policies investigated with the modeling system include:

- highway and transit improvements;
- highway and transit improvements plus subsidized transit with increased parking fees;
- transit-oriented development (TOD) consisting of transit improvements, subsidized transit, increased parking fees, plus mixed use centers, medium to high density housing with commercial cores near light rail alignments, and medium density housing with convenience shopping; and
- TOD plus congestion pricing for automobile work trips.

The analysis projected that the TOD alternative would lead to a more than a doubling of work trips by transit, with about half the increase due to the land use component, and about half to the

[2] Census tracts are defined by the Bureau of the Census to have approximately equal populations: about 4000 each.

transit subsidy component. A significant increase in carpooling was also projected due to the increase in parking fees.

As part of the LUTRAQ study, results obtained using a linked configuration of DRAM/EMPAL with the travel demand model (i.e., iteration of the modeling systems to achieve equilibrium travel times) were compared using a traditional configuration (i.e., fixed travel times input to DRAM/EMPAL). This exercise was performed with two different spatial resolutions of analysis zones. The findings included the following:

- Numerical results for zone-to-zone trips and travel times differed for the two spatial resolutions. The authors conclude that at coarser geographic resolutions significant portions of the region's trips are missed, so that network congestion is underestimated. Thus, the choice of zone size can affect the accuracy of the resulting travel assignments.

- The degree to which linked model results differ from those obtained with the traditional procedure depends on the amount of network congestion, which can be underestimated if the geographic resolution of zones is too coarse.

San Diego Association Of Governments (SANDAG)

The San Diego Association of Governments (SANDAG) has been producing short-range and long-range forecasts of growth in population, employment, and housing in the region since 1971. The forecast is one input to the Regional Transportation Plan and is used to conduct project reviews under the Intergovernmental Review process. Other uses of the forecast include assessing the impacts of growth, projecting the changes in public service levels, and assessing the need for new or expanded (reduced) public facilities.

Land use modeling for SANDAG is done in two phases with four major modules. First, the Demographic and Economic Forecasting Model (DEFM) produces region-wide projections of population, employment, housing, and more than 700 variables. The second phase employs three allocation models to distribute the region-wide forecast to smaller areas: Putman's EMPAL, the Projective Land Use Model (PLUM), and the Sophisticated Allocation Process (SOAP). The EMPAL model is used to distribute the total regional employment to 204 Zones for Urban Modeling (ZUMs), according to attractions and constraints that are derived from employment concentrations and planned land uses. Using inputs from EMPAL, the PLUM model allocates population and housing units to ZUMs based on the location of projected employment, the availability of useable land and transportation accessibility. Finally, the SOAP model refines the geographic distribution even further by distributing housing and employment to smaller geographic areas called Master Geographic Reference Areas (MGRAs). The 25,915 MGRAs are constructed from the region's census blocks, census tracts, community planning areas, city boundaries, spheres of influence and zip codes. PLUM and SOAP include redevelopment and infill options as part of their allocation procedures. These are important features for evaluating policies that encourage increases in development density.

The sub-regional allocation performed by the EMPAL, PLUM and SOAP models requires a detailed data base. Information on population, housing, employment, income and land use are needed. The population and housing variables include: employed residents, non-working residents, military population, total housing units, occupied units, military units, and structure type. The employment inventory consists of more than 76,000 work sites, their employment totals, their geographic attributes and their Standard Industrial Classification (SIC) Codes. The transit data used include transportation policy assumptions and transportation networks. Existing and planned road networks, freeways, expressways, major arterials, and transit routes are all incorporated into sub-regional connectivity patterns. Travel modes include work-to-home, home-to-shop and work-to-shop trip types and public transit. Travel time distribution probabilities and parameters are based on data from the 1986 Travel Behavior Survey conducted by SANDAG, calibrated to 1990 traffic counts.

SANDAG uses population and housing data from the land use modeling system as input to their travel demand model, TRANPLAN. Additional data input requirements include transportation network links, which are maintained using ARCINFO GIS software. SANDAG's travel demand modeling process applies the standard four-step procedure (trip generation, distribution, mode choice, and assignment). Surveys are conducted periodically to calibrate relationships used within the models.

Policies evaluated with the travel demand model include long-range plan development, transportation conformity, corridor studies, and impact analyses.

Puget Sound Regional Council (PSRC)

The PSRC was one of the first users in the nation of the DRAM/EMPAL land use software, which it acquired in 1980. Since then the models have been progressively restructured, reprogrammed, and enhanced. Modifications have included structural changes in the calibration and forecasting equations, development of a composite cost travel impedance (travel time and out-of-pocket costs), and addition of submodels to predict single/multi-family housing distribution and residential land consumption. The models are used for long-range small-area population and employment forecasts, inputs to travel demand models, and impact analysis of transit development and public facility siting alternatives.

The first step in the modeling procedure used by PSRC is to allocate regional and national population, household, and employment forecasts to subregions with an in-house econometric model. The population, housing and employment projections are then entered into DRAM/EMPAL along with land use, impedance, and accessibility data. Once the modeling is complete, the outputs from DRAM/EMPAL are reviewed by a modeling subcommittee for quality assurance purposes.

PSRC maintains DRAM/EMPAL on PCs in-house without the services of Putman and Associates. They report that they need to run it only every 2 or 3 years. Simply running the models is not difficult, but applying the land use forecasting portion requires expertise.

The outputs from DRAM/EMPAL are entered into PSRC's travel demand model, EMME2. A FORTRAN program is used to distribute the household and employment from the 229 forecast analysis zones to the 832 traffic analysis zones, used in the 4-step process. Once the model is calibrated and all necessary inputs are prepared, EMME2 is run. The outputs are then used by PSRC for transportation improvement program evaluations, air quality conformity analyses, congestion management, HOV analyses and non-motorized mode planning.

PSRC has used DRAM/EMPAL in iteration with an earlier travel demand model (UTPS) in the evaluation of alternative long-range development policies (Watterson, 1990). At least two full cycles were performed for each alternative, which included both concentrated and dispersed employment, as well as transportation infrastructure investments. The modeling results showed that the land use policies had only a weak impact on household locations, suggesting either that travel-to-work behavior is relatively insensitive to land use changes or that the models do not capture the sensitivity well.

North Central Texas Council of Governments (NCTCOG) of The Dallas-Fort Worth area

NCTCOG uses the DRAM/EMPAL model in-house, with consulting services provided by Putman and Associates. The model is used in conjunction with transportation plan information and expertise from local governments to forecast population and employment in five-year increments. The model utilizes a 191-zone system, that is being expanded to 300 zones in an attempt to improve the sensitivity to congested travel time data provided by NCTCOG's in-house travel demand model. Outputs are currently passed between DRAM/EMPAL and the travel demand model as part of the modeling procedure, as described below. There are plans to explicitly link the models in the future.

The travel demand model developed by NCTCOG consists of a series of FORTRAN programs designed to perform the sequential four-step modeling process of trip generation, distribution, mode choice and trip assignment. The system, called the Dallas-Fort Worth Regional Travel Model, runs on an IBM mainframe computer. The mode choice element of the model includes light rail, HOV travel, peak and off-peak travel, Levels of Service, congestion delay, and toll roads. The travel demand system is configured with 920 zones, an aggregation of 6000 smaller zones. To support the travel demand model, NCTCOG has assembled a special information collection and dissemination team, which has conducted surveys of employers, travel diaries, travel time, vehicle occupancy, and parking. They report that specialized training and expertise are required to operate the travel demand model. Policies evaluated include corridor analysis, rail project evaluation, capacity increases, HOV lanes, toll roads, transportation conformity, and major investment studies.

NCTCOG's modeling procedures include a feedback between the trip assignment stage in the travel demand modeling and the land use model. First, DRAM/EMPAL is run to provide an initial base year forecast of land use. Next, the 4-step travel demand procedure is completed to develop base year travel times. These travel times are then fed back into DRAM and EMPAL to determine land use allocation changes.

Sacramento Area Council of Governments (SACOG)

Current land use projections are developed by SACOG through a consensus building process with local planning departments using adopted general plans, local expertise on development activity, and state Department of Finance population projections. SACOG is considering integrating the DRAM/EMPAL model into this land use forecasting process.

If DRAM/EMPAL is adopted by SACOG, it will project land uses for 127 zones in four counties. The agency has spent considerable effort setting up DRAM/EMPAL and preparing a reliable data base for use within the model. If the model is used, the employment and population results would input to their SACMET travel demand model, which is composed of MINUTP and two network models. The travel model network has 1,100 traffic analysis zones and over 14,000 links. Non-motorized modes have been incorporated, as have peak and off-peak data. A household travel survey was used to calibrate the model. Policies evaluated with modeling include long-range plan development, air quality conformity, corridor studies, impact analyses.

Houston-Galveston Area Council (H-GAC)

H-GAC uses the DRAM/EMPAL model for land use projections for 199 zones. The system was originally installed by Putman and Associates, but H-GAC now uses it without their services. It runs on a 486 PC. H-GAC staff have made several refinements to the modeling system including writing a number of adjunct computer programs to enhance the allocation procedure, allowing it to capture several locally-significant variables. H-GAC reports that DRAM/EMPAL is not a user-friendly program, and that it requires training and experience in order to be able to run it. They have developed a user-interface to make it easier to operate and to provide analytical output. The models are used to evaluate transportation planning policies. H-GAC has had problems with the DRAM/EMPAL programming code and as a result are actively seeking a replacement for DRAM/EMPAL.

H-GAC currently uses the Texas Travel Demand Forecasting Package, developed for the Texas DOT and maintained by the Texas Transportation Institute. They are in the process of converting to a UNIX-based EMME2 transportation planning software. The travel demand system includes 2600 traffic analysis zones. The effort has been supported by household surveys in 1985 and 1995. H-GAC reports that running the travel demand modeling system requires extensive training and specialized knowledge.

Currently there is no feedback between the land use and travel demand modeling systems. However, there are plans to develop such a mechanism in the future. H-GAC has had problems with disaggregation between the land use and transportation modeling systems.

Southern California Association of Governments (SCAG)

SCAG previously used DRAM/EMPAL modeling as a supplement to the expert judgment of local planning agencies for land use forecasting. They are now using expert judgment combined with a small area allocation model, developed in-house, and geographic information system software (GIS). Data requirements include US Census data, local and regional socioeconomic data, and US Census geography data for GIS, including existing land use and future land use data in digital form. Implementation is done by GIS analysts, demographers, programmers and modeling analysts. All general land use plan policies are evaluated with the system.

Travel demand modeling is done with a customized version of TRANPLAN. Modifications include SCAG-specific trip generation and mode split elements, and changes in the network assignment procedures. TRANPLAN simulation results are used as input to DTIM, which projects regionwide pollutant emissions. Policies evaluated include the long-range plan, transportation improvement programs, corridor studies, and air quality conformity. Currently, there is no integrated feedback mechanism between the land use projections and travel demand modeling.

Denver Regional Council Of Governments (DRCOG)

DRCOG uses a pc-based land use model that allows them to look at alternative land-use forecasts and policy alternatives. The major strength of the model is that they can make policy-related forecasts. The main shortcoming of the tool is that some of the policy variables used in the model cannot be calibrated. DRCOG considered using DRAM/EMPAL but judged that it would not address the policy variables of interest to them. The data requirements of the land use spreadsheet include population, population growth rates, number of households, employment, current land use, vacancy rates, density, access to open space and transit, economic constraints, and policy variables. Most of these data are estimates made by DRCOG based upon forecasts of US Census data. GIS software (ARC/INFO, ATLAS GIS) is used for viewing current land uses and creating buffer zones for analysis.

Output from the land use spreadsheet is entered into DRCOG's travel demand model. Run on a personal computer, using the MINUTP software, DRCOG's model is capable of estimating the number of vehicles on a future freeway, passengers on a new bus service, riders on a new rapid transit line, or the response to certain travel demand management policies. The model was calibrated with information collected in a 1985 household travel patterns survey and a 1986 on-board bus survey. These surveys recorded the number of trips, trip purpose, origin, destination, travel mode, how transit was accessed, and trip time of day. The model is very data intensive. The output is used to prepare long-range plans, transportation improvement programs, major investment studies, and to compare various project alternatives. There is currently no feedback between the land use and travel demand models, but a lagged variable feedback procedure is in development.

East-West Gateway Coordinating Council (St. Louis)

The East-West Gateway Coordinating Council is currently using historically-based algorithms to project spatial allocations of population and employment, instead of a land use model. Travel demand analysis is performed with a standard version of MINUTP, run on PC. They report that the modeling system requires extensive training and specialized knowledge. Policies evaluated include major investments, TIPs, and air quality conformity.

Feedback between the land use projections and travel demand is incorporated into the MINUTP routine through a cyclical process that takes the congested times calculated during the assignment phase back to the path building module for re-input into trip distribution. The interaction between future transportation investments and land use development is currently not taken into consideration, although they are researching ways to incorporate this relationship into the transportation modeling process. They are also developing linkage between MINUTP and GIS, with current emphasis on presentation applications.

Wasatch Front Regional Council (WFRC), Salt Lake/Ogden, Utah

WFRC does not use a model for land use projections. Instead, travel demand model input data pertaining to buildings, employment, and population are collected from local building permits, the State Office of Employment Services, and the Office of Planning and Budget.

MINUTP, run on a PC, is used to make travel demand forecasts for 500-plus zones in Salt Lake and 200-plus zones in Ogden. Currently WFRC uses separate models for Salt Lake and Ogden. Trip generation is determined using regression models to forecast person trips by six trip purposes. A multi-purpose gravity model is used for trip distribution and a logit model is used for mode choice. The traffic assignment model performs several iterations of equilibration using a 24-hour trip table. WFRC reports that preparing the data and executing these steps using the

MINUTP software requires some training. Model results are used to evaluate roadway infrastructure improvements, and perform air quality conformity studies.

Northeast Ohio Areawide Coordinating Agency (NOACA), Cleveland, Ohio

NOACA uses a combination of modeling tools and analysis techniques to do their land use forecasting. Regional population is forecasted using a Cohort Survival Model which requires economic activity and state population data as inputs. Future employment levels are predicted using employment growth rates by employment category. A regression model is used to forecast average household income by traffic analysis zone. NOACA's land use forecasting procedure involves using the forecasted employment and household data along with published development plans in the region and the City and County Planning Commissions' analyses to make land use determinations.

NOACA uses the traditional 4-step modeling process to complete its travel demand modeling. The agency completes the trip generation and mode split portions of the process off-model. The trip distribution and network assignment steps are completed using Tranplan software run on a personal computer. NOACA is in the process of enhancing the Tranplan model so as to be able to look at HOV, pricing policies, signal preemption, and other TCMs. As part of the model improvement process, they plan on adding walk and bike to the vehicle and public transit modes which are currently modeled. They also hope the new model will enable them to do peak-hour assignments - the current model is just 24 hour assignment.

5 EVALUATION OF MODELING TOOLS

DRAM/EMPAL

The **D**isaggregated **R**esidential **A**llocation **M**odel (**DRAM**) of household location and the **Emp**loyment **Al**location Model (**EMPAL**) of employment location were developed by S.H. Putman and Associates. A license fee of approximately $50,000 covers one year of implementation support, including model preparation and staff training. For an additional $5000 annually technical support by telephone is provided. Putman and Associates typically guide agency staff through the first calibrations of the models for the region. After checking and revising input data, where necessary, final calibrations are often done by agency staff with only limited assistance from Putman and Associates. The model may be run on a PC.

The DRAM and EMPAL models have been applied to more than forty metropolitan regions, varying greatly in size. The largest is the Los Angeles metropolitan region, with population in excess of 14.5 million. The smallest is Colorado Springs metropolitan region, with a population under 400,000.

The experience of agencies with this model, clearly the most widely used land use model in the US, vary (see case studies in Chapter 4). Successful calibration depends upon the quality of input data. Thus, development of the data base for two previous years is likely to be the most resource intensive task in application of the model. At least one MPO considered the modeling system to be difficult to run, and developed a their own user-interface to simplify operations.

Development of the model is described in detail in Putman, S. *Integrated Urban Models* (1983, Pion Limited, London) available from the publisher.

Formulation of DRAM/EMPAL

Like most land use models in use today, DRAM/EMPAL is derived from what is known as the Lowry Model, developed by Ira Lowry in the mid-1960s. Application of the modeling system first involves dividing the urban area into an exhaustive set of spatially contiguous zones, usually 100 to 300, which are aggregations of census tracts. Total employment (place-of-work) is disaggregated into 4 to 8 economic sectors, e.g., industrial, manufacturing, services, retail. Households (place-of-residence) are similarly disaggregated into 4 to 8 income groups.

The EMPAL model forecasts the locations of future employment in each zone, by economic sector, on the basis of the following exogenous variables:

- Level of base year employment in the zone, total and by economic sector
- Number of base year households in each zone, by income level
- Level of target year employment
- Travel time, or other impedance measure, between zones
- Total land area of each zone

Calibration is performed with a submodel, CALIB, and consists of estimating the historical relationships between employment in each zone and the exogenous variables. This is accomplished with a gradient search procedure, analogous to regression analysis, but with different mathematics to address nonlinearity of equations. The results are then modified with user-specified adjustment factors (K-factors) to correct calibration errors and reflect special cases. Finally, the results are adjusted to conform to any zonal employment capacity limits specified.

Thus, selection of a zone for a site of future employment is projected on the basis of how often it was selected in the past, given the distribution of households (potential employees) and accessibility of the zone from other zones. In some sense this formulation represents a worker's choice of workplace location.

DRAM then forecasts the future location of households, by income level, given the distribution of employment, similarly on the basis of the following exogenous variables:

- Base year amount of residential land, vacant land that can be developed, and percentage of land already developed in each zone
- Level of target year employment in each zone, by economic sector (from EMPAL)
- Level of target year population
- Number of target year person trips by purpose (i.e., work-to-home, work-to-shop, home-to-shop)
- Travel time, or other impedance measure, between zones

DRAM also generates trips for three purposes: home-to-work, home-to-shop, and work-to-shop. When DRAM/EMPAL are applied as part of the **I**ntegrated **T**ransportation and **L**and **U**se **P**ackage, or **ITLUP**, the generated trips are then distributed, split into modes, and assigned with modeling tools similar to those used in the standard travel demand module, and requiring the same type of input data. In principle the three components of the system (EMPAL, DRAM, and the travel demand modules) can be iterated to find an equilibrium solution with consistent impedances, although this is seldom done in practice, due to resource requirements. An overview of the ITLUP package is illustrated in Figure 5.

Note that EMPAL and DRAM project land use activity, i.e., employment and households, in each zone, but not land consumption. These estimates are made with a separate submodel, LANCON, on the basis of past relationships between land use activity and land consumption, i.e. historical development densities for various activities.

Specific input data requirements for DRAM/EMPAL

Data for the DRAM/EMPAL modeling system are required both for the region, or overall modeling domain, and for each analysis zone. At the regional level EMPAL requires target year values of total employment by economic sector, and DRAM requires target year values of

total population;
total person trips by purpose (i.e., work-to-home, work-to-shop, home-to-shop);
percent unemployment, by sector;
employees per household, by household type;
matrix of households by income per employee by sector;
jobs per employee; and
net regional rate of employee commuting.

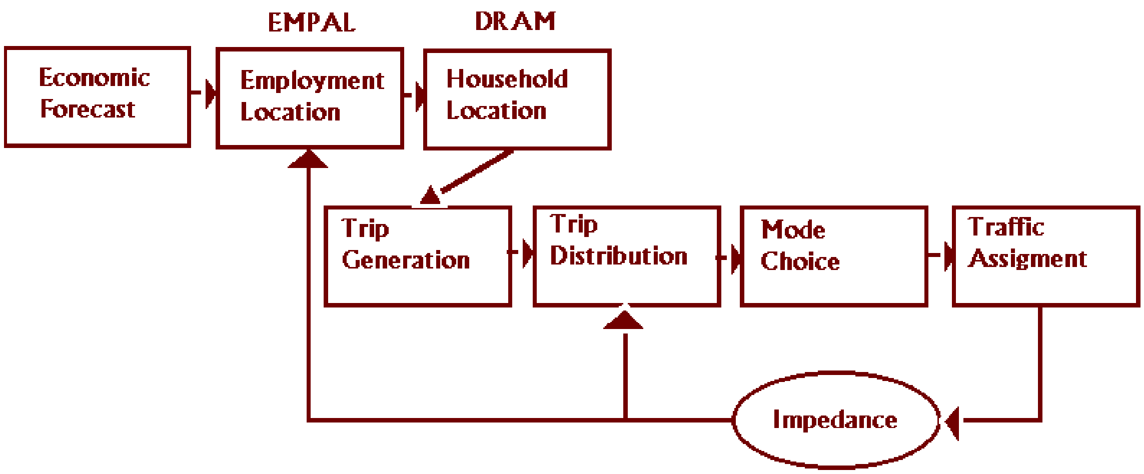

Figure 5. Overview of the S.H. Putman's Integrated Land Use and Transportation Package (ITLUP).

At the analysis zone level EMPAL requires base year values for:

- households, by type;
- employment by sector;
- total land area;
- land area occupied by basic and commercial employment; and
- zone-to-zone travel times and/or costs;

and DRAM requires base year values for:

- households, by type;
- total population;
- total employed residents;
- group quarters population;
- land area by use (i.e., basic and commercial employment, residential, streets and highways, developable, undevelopable);
- land area occupied by basic and commercial employment;
- employment, by sector; and
- zone-to-zone travel times and/or costs.

DRAM/EMPAL outputs

The EMPAL model projects employment (place-of-work) in each zone, by economic sector. The DRAM model projects the number of households in each zone, by income level. In addition, LANCON projects the consumption of land in each zone.

Assessing Land Use Policies with DRAM/EMPAL

Can the DRAM/EMPAL modeling system represent the target land use policies, and evaluate their effectiveness in achieving land use strategy objectives, such as higher development densities, high density development near transit stops, mixed used development?

It was noted above that the policies for encouraging higher density and mixed use are of three types:

1. zoning;
2. monetary incentives; and
3. non-monetary incentives.

Zoning As noted above, land consumption corresponding to land use activities is estimated in the LANCON submodel on the basis of historical relationships. Thus, the parameters estimated for the LANCON equations define the density projections for land use activities. Implementation of zoning for higher density, would likely involve exogenous modifications of the parameter estimates in LANCON. DRAM/EMPAL contains no behavioral assumptions that pertain to the effectiveness of various zoning regulation approaches, e.g., allowing higher density, setting minimum densities. In particular, the response of developers to minimum density requirements near transit stops would have to be determined outside of the modeling framework.

Zoning for mixed use might involve requirements for concurrent allocation of new land use activities of different types to the same zone, or allocation of new land use activities to zones that currently have little of such activity. Without reformulation of the basic equations, such policies could only be represented as constraints, similar to capacity constraints, which are checked for violation at the end of the modeling process.

In summary, as currently formulated DRAM/EMPAL is not well-suited for evaluation of the impact of the candidate zoning policies on achieving the land use strategy objectives.

Monetary Incentives DRAM/EMPAL has no direct representation of costs in employment or residential location decisions[3] (except in cases where out-of-pocket costs have been added to travel time to create a composite travel costs). Thus, monetary incentives to guide land use development cannot be represented with DRAM/EMPAL as currently formulated.

Non-monetary incentives/disincentives Some non-monetary incentives, such as reduced parking requirements or accelerated permit processing, are designed to lower costs for developers. Therefore, developers responses would be similar to those for monetary incentives, which cannot be represented in the DRAM/EMPAL models as currently formulated, and would have to be assessed outside of the model.

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[3] Although the current formulations have no explicit economic variables, such as price or land value, the disaggregation of data into employment sectors and income groups may implicitly address land value to some extent. In any case, adding "land value" as an independent variable to the DRAM formulation is under consideration. The proposed "land values" are relative house prices, possibly in the form of a multi-variate house index giving consideration to single and multi-family structures.

An incentive such as an infrastructure upgrade that resulted in reduced travel impedance, suitably estimated with a travel demand model, could be represented in the models and influence locational choice. Similarly, parking restrictions can be represented as increased travel impedance within the models. Two types of limitations may impede the accurate evaluation of these policies with DRAM/EMPAL. The first is the spatial scale of the analysis zones. If this is significantly larger than the scale of application of the policies, detection of any impact would be difficult. Limitations on the spatial resolution of analysis zones may be due to data availability and/or model formulation issues. A more detailed discussion of the spatial resolution issue is presented in the following section.

The second type of limitation in evaluating infrastructure improvements that reduce travel impedance is the limited number of independent variables used to make projections in the DRAM/EMPAL modeling system. The result may be an underestimate of the full impact of some infrastructure improvements, such as a pedestrian-friendly environment attracting additional households. The DRAM/EMPAL modeling formulation considers primarily the spatial distribution of employment and housing, and travel impedances in making location projections. Any special features of a zone that have affected its attractiveness in the past are implicitly included the subsequent adjustments with K-factors. The K-factors are typically applied to future year forecasts without modification, under the assumption that the unexplained variation will continue to affect activity location in the future. Alternatively, their effect may also be attenuated over successive forecast time periods. However, an increase in "special attractiveness" of a zone due to addition of features like pedestrian-friendly environments, will not be captured without exogenous modifications of the K-factors. Thus, a policy to increase density in an area by attracting households with special features will not be reflected in the modeling projections, except to the extent that they affect travel impedance.

Assessing Land Use Strategies with DRAM/EMPAL

Can the DRAM/EMPAL modeling system evaluate the impact of the strategy (e.g., higher density, mixed use) on trips and/or VMT?

As discussed in Chapter 3, both land use models and transportation models formulate the modeling areas as a set of contiguous zones. The spatial resolution of the zones in DRAM/EMPAL is limited by a number of factors. Required data, especially employment (place-of-work) by economic sector, may be available only at a coarse level of resolution. An additional factor pertains to the calibration procedure, accomplished with a mathematical procedure similar to regression analysis. Better goodness-of-fit and parameter estimates are made when the independent variables are strongly correlated with the dependent variables (e.g., households in each zone). If zones are defined by census tracts, however, there is little variation in household totals, because census tracts are specified to have approximately equal populations. This leads to calibration difficulties because low variation in either independent or dependent variables decreases the chances of detecting strong correlations. Thus, census tract resolution of analysis zones was cited as one of the factors leading to poor calibration results for the DRAM/EMPAL application in the LUTRAQ study of Portland, discussed in Chapter 4. In other applications (e.g., Detroit) DRAM/EMPAL has used analysis zones that are aggregations of several census tracts.

The result of these limitations on spatial resolution is that DRAM/EMPAL analysis zones typically are significantly larger than the travel demand model analysis zones, requiring additional processing to disaggregate the land use projections. (See discussions of SANDAG, PSRC, NCTCOG, SACOG, and H-GAC in Chapter 4).

The average size of an urban census tract is about 2 square kilometers. With an analysis zone of this size it may be possible to detect, for example, increased density within 0.5 to 1.0 kilometers of a transit station, or transit corridor (strategies 5 and 6). However, for larger zones that are aggregations of census tracts, such microscale development characteristics may not be distinguishable. A similar problem pertains to the representation of mixed use and/or pedestrian friendly site design (strategies 1 and 3). Because the objective of such designs are to encourage pedestrian traffic modes, they are necessarily specified at a very fine spatial scale corresponding to walking distances. But even if a variety of land uses are projected to occur in a large zone, without further analysis it is not clear how to determine whether the configuration constitutes mixed land use development that encourages walking. Increased density at larger spatial scales, such as infill/densification and strong downtowns (strategies 1 and 2), may be represented, but the mixed use characteristics will still be obscure.

Thus, if the DRAM/EMPAL modeling system is implemented with analysis zones that are census tracts, assuming that all required data are available at this resolution, calibration may be unsuccessful. If it is implemented with analysis zones larger than census tracts, as is typically the case, the target land use strategies will not be well represented within the DRAM/EMPAL modeling framework. In that case, the assessment of the density and/or mixed configuration of land use activities will be accomplished by whatever procedure is used to disaggregate the information from the land use analysis zones to traffic analysis zones, i.e., outside of the DRAM/EMPAL modeling system.[4]

MEPLAN and TRANUS

The MEPLAN model was developed by Marcial Echenique and colleagues at the Center for Land Use and Built Form Studies at University of Cambridge, at Applied Research of Cambridge, and currently at the firm of Marcial Echenique and Partners. A similar model, the **TRAN**sporte **U**so del **S**uelo (TRANUS) model was developed by one of Echenique's colleagues, Tomas de la Barra, now of the Venezuelan firm Modelistica. The cost of the complete MEPLAN system is $15,500 with an additional $4,650 for an associated graphics system. Modelistica provides an unlimited TRANUS site license for $6,000. This fee includes software, documentation, one year of (email) support, and free updates as they become available. Annual extensions may be arranged for 40 percent of the cost of the license per year. Training and consulting assistance are also available for additional fees.

MEPLAN has been applied in numerous metropolitan areas outside of the US, including London and Southeast England; Cambridgeshire, UK (Echenique et al, 1987); Bilbao, Spain, Sao Paulo, Brazil (Echenique, 1985); Caracas, Venezuela (Feo et al., 1975); central Chile (de la Barra et al., 1975), and Naples, Italy (Hunt, 1994). TRANUS has been exercised for the island of Curacao, the city of La Victoria, Venezuela, and the city of Caracas. It has recently been applied to the Sacramento, CA metropolitan area (Johnston and de la Barra, 1996).

Development of the TRANUS model is described in de la Barra's *Integrated Land Use*

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[4] Note that the LUTRAQ study, discussed above, found that the use of large analysis zones can also lead to significant underestimation of the number of trips and, hence, the level of network congestion.

and Transport Modeling, Cambridge University Press, 1989.

Overview of MEPLAN and TRANUS

The MEPLAN and TRANUS models integrate economic theory with operational planning methods. The basis of the framework is the interaction of two parallel markets; one for land and one for transport. The land portion of the model predicts volumes and locations of activities and their economic linkages with a formulation that explicitly considers costs of land and development. The economic linkages include goods, services, and labor. These are then used to project travel demand, both passenger and freight, which are assigned to modes and routes on the basis of travel impedance measures. These travel impedances then influence the location of activities in future time periods. Thus, the modeling system is applied so that land use is influenced by the pattern of use in the prior period and by previous period transport accessibilities; and transport is influenced by previous infrastructure and present activity patterns arising from land use.

The MEPLAN and TRANUS modeling approach is derived from Economic Base theory (North, 1955). Using this approach, exogenous forecasts of "basic" employment (i.e., that directed to production of goods for export from the region) are used to project the study area population and overall employment. New increments to basic employment are allocated to zones based on zone attributes, such as available land and previous basic employment. New increments of floorspace for basic employment are also allocated to zones, based on potential profitability and zoning regulation constraints.

Households and non-basic employment are then allocated to zones on the basis of costs of travel, floor space, and other goods and services. In these economic-based models, the desire for accessibility leads to higher rents for the most accessible locations, resulting in a segregation of land uses, based upon the differential ability of activities to pay rent. The process is represented in the model with a "bid-rent function," which describes how much each activity is willing to pay for each location. Each location is assumed to be rented to the highest bidder. The resulting spatial allocations of activities generate travel demands. For both models the calibration process is complex and usually is the most time-consuming activity in the project. Hunt (1993) describes selecting parameters for MEPLAN as " a trial and re-trial process involving the entire model". He notes that some of the procedures have been incorporated into the commercially available model package, but that "others must be made manually be experienced personnel". A similar process is required for TRANUS, where parameter estimates are modified until the simulated results match available data (Modelistica, 1996).

Formulation of MEPLAN and TRANUS

These models represent the metropolitan economy as composed of:

- Basic production, for goods exported from the region;
- Non-basic production, for goods and services consumed locally, both by households and other businesses; and
- Households, which supply labor and consume goods and services.

The interactions of these components are simulated in three systems: (1) projection of basic or overall employment, or households; (2) spatial allocation of basic employment, non-basic employment, and households, while tracking transportation flows; and (3) matching transportation flows with transportation network elements to estimate accessibility between zones.

For the first system, the models rely on input/output modeling techniques to estimate the number of households and the level of non-basic employment that are consistent with the exogenous level of basic employment. An economic input/output matrix is constructed which specifies the activity-to-activity relationships for a set of economic activities, defined to fit the region and data. The relationships may take the form of elastic (demand) functions, if sufficient data are available, or constant ratios. A typical application may include 4 residential activities (households of varying income levels), 3 non-basic employment activities, and 2 basic employment activities. The matrix specifies how much of each activity is required to produce 1 unit of output of a given activity. For example, output of basic industries requires labor, and, therefore, the presence of a certain number of households. Each household requires services, an output of the non-basic industries.

The land use allocation portions of MEPLAN consists of two parts. The incremental portion spatially allocates basic employment to zones in a manner similar to DRAM/EMPAL. In the land market equilibrium portion both non-basic employment and households are allocated among zones which comprise the metropolitan area. Floor space constraints in each zone vary endogenously according to the dynamics of the land market, i.e. when there is sufficient developmental pressure in a zone, additional floor space can be created, but still subject to zoning constraints. In TRANUS all employment and households participate in the land market.

In the process of allocating land use activities to zones, potential interzone flows of goods and travel are also projected. This obviates the need for a trip distribution step in the transportation portion of the model, since "trade flows" can be directly translated into potential modal volumes. Exogenous trips (to and from locations outside of the modeling domain) may also be added.

The transportation portions of MEPLAN and TRANUS address mode choice and trip assignment on the basis of composite cost, and in this respect is similar to the standard travel demand formulations. The TRANUS model has a more complex algorithm for route choice, however, which is consistent with a random utility formulation, so that trips are not simply assigned to the least cost routes, but are distributed among a set of low cost routes. The result is that traffic on least cost paths is less likely to be overestimated.

In MEPLAN and TRANUS there is lagged feedback from the trip assignment step to trip generation in the next time step, through changes in composite travel cost (time plus out-of-pocket costs) which influence the actual number of trips made. Thus, increased congestion reduces the number of trips in the next time step, while new transportation facilities generate a certain amount of induced demand.

The general structure of these models is illustrated in Figure 6.

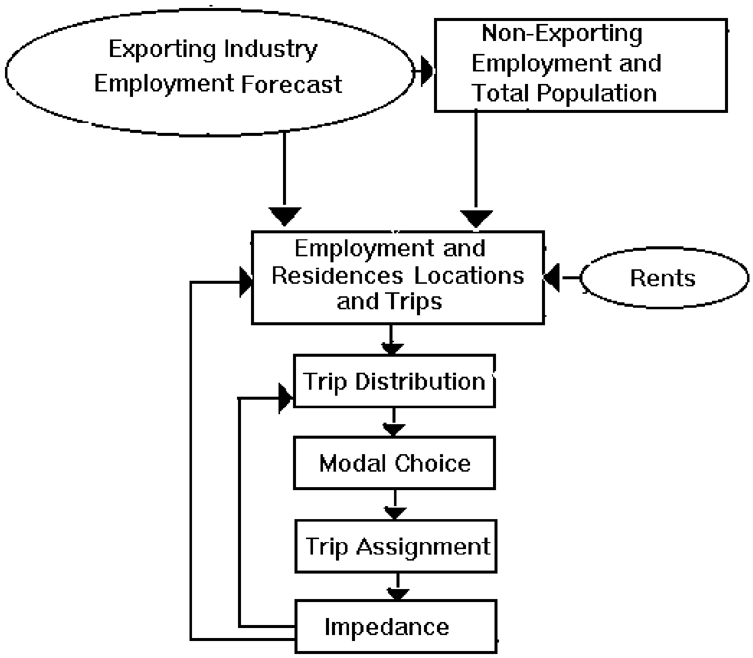

Figure 6. Overview of the MEPLAN and TRANUS land use-transportation models.

Within the general framework, travel modes, household groups, and industrial sectors are tailored to the target region. Options include walk and mixed modal trips; combined freight and passenger flows; the modeling of work, education, shopping, and other nonwork trips, and home delivery of goods. In a recent application of TRANUS to Sacramento, CA modification of the transportation formulation allowed the representation of mode combinations for travel, such as bicycle, park&ride, and bus (Modelistica, 1996).

An interesting feature of TRANUS is its ability to use a nested zone configuration, with finer spatial resolution in selected parts of the modeling domain. This feature may prove useful for evaluating some of the policies and strategies discussed above that are targeted at areas the size of a census tract or smaller. However, in a typical application even the nested zones include several census tracts.

MEPLAN contains an additional module that performs cost-benefit analysis, including social and environmental indicators. The TRANUS package includes a graphical user interface for editing the transportation network specification.

Specific Input Data Requirements for MEPLAN and TRANUS

For both models the data requirements for calibration are great. For example, according to Johnston and de la Barra (1996) TRANUS requires the following for calibration of the base year or years.

Land Use:

- number of households by income class by zone
- average number of people per household by income class
- average acres per dwelling by income class by zone,
- average acres per employee by type by zone,
- land sales prices by land use and density
- land use designations in local plans by zone,
- number of employees by type and residence zone
- number of employees by income class and work zone
- average income per capita by income class
- household expenditures for land, travel, retail, other
- flows of school children by residence zone/school zone combinations and income class

Transport

- road counts
- public transport route counts
- walk, wait , and ride time by mode
- average parking cost by zone
- free flow speeds by link type
- transit fares
- operating costs by transit operator
- operating costs by auto user
- fuel consumption
- average occupancy for auto by trip purpose
- average occupancy for transit
- car availability by trip purpose and household income class
- number of trips by zone pair
- proportion of trip in morning peak by purpose
- cordon volumes

The data requirements for subsequent time periods are quite modest, however.

Land Use

- allowable growth in each land use by zone
- building density caps by land use by zone
- projections of total or basic regional employment

Transport

- network changes
- changes in transit headways and fares

- roadway tolls
- parking charges

Specific MEPLAN and TRANUS Outputs

Many disaggregated outputs are available. For example, zonal outputs of MEPLAN include employment by sector, population by income group, households by car ownership group, land area by activity, floor space by activity, trips and travel time for each origin/destination pair by income group.

Assessing Land Use Policies with MEPLAN and TRANUS

Can the MEPLAN and TRANUS modeling systems represent the target land use policies, and evaluate their effectiveness in achieving land use strategy objectives, such as higher development densities, high density development near transit stops, mixed used development?

It was noted above that the policies for encouraging higher density and mixed use are of three types:

- zoning and other types of regulations;
- monetary incentives; and
- non-monetary incentives.

<u>Zoning</u> As noted above, development of floor space is projected endogenously on the basis of potential profitability, subject to zoning restrictions. These restrictions take the form of maximum allowed floor space for each activity type in each zone. Thus, policies encouraging higher density overall in the zone by relaxing maxima could be represented. MEPLAN also includes parameters specifying the floor space per land area in each zone and the cost of building a unit of floor space, which should vary according to the floor/land ratio. These parameters could be specified to reflect the variation in costs and land consumption that correspond to various zoning requirements, including minimum densities for new development. In both cases, varying the parameters should influence the resulting land use patterns, so that an estimate of the effectiveness of the policies could be made. However, these parameters can only be specified at the zonal level. Therefore, targeting density-increasing zoning to specific locations, such as near transit stops, cannot be represented without quite small analysis zone sizes.

Mixed use might involve concurrent allocation of new land use activities of different types to the same zone, or allocation of new land use activities to zones that currently have little of such activity. At the zonal level, zoning policies that encourage mixed development could be represented by manipulation of floor space zoning maxima for various activities among zones. However, because the model formulation determines the location of new development for the various activities separately, the extent to which land uses mix at the micro-scale level (i.e., smaller than zones) cannot be addressed. Thus, the size of the analysis zones will be an important consideration in evaluating policies to encourage mixed land use designed to facilitate pedestrian travel.

<u>Monetary Incentives</u> Because development of new floor space is projected, in part, on the basis of development costs, policies that offer monetary incentives to developers to build in targeted zones or at specified minimum densities could be represented in the models in terms of decreased

development costs. Again, these can only be specified at the zonal level, so that the size of the zones is an important consideration for evaluating policies that target small scale development characteristics.

Non-monetary incentives/disincentives Some non-monetary incentives, such as reduced parking requirements or accelerated permit processing, are designed to lower costs for developers. Therefore, these types of policies could be represented similarly to policies of monetary incentives, with similar developers responses.

An incentive such as an infrastructure upgrade that resulted in reduced travel impedance, suitably estimated with a travel demand model, could also be represented in the models and influence floor space demand, which in turn influences developer responses. Similarly, parking restrictions can be represented as increased travel impedance within the models. Again, however, the spatial scale of application of these policies may be significantly smaller than the scale of the analysis zones, so that detection of any impact would be difficult.

Note that there although there are more independent variables used to make land use projections in MEPLAN and TRANUS than in DRAM/EMPAL, the number is still limited. This limitation may similarly lead to underestimates of the full impact of some infrastructure improvements, such as a pedestrian-friendly environment attracting additional households. Like DRAM/EMPAL the formulation considers composite travel impedance (time and out-of pocket costs) and past attractivity. In addition costs of floor space are considered. However, an increase in the attractiveness of a zone due to addition of special features like pedestrian-friendly environments, will not be captured unless an attractiveness factor for the special feature is added to the formulation and its impact determined by calibration with historical data. That is, sufficient data must be available to quantify the relationship between the presence of the special feature and the attractiveness of the area. Otherwise, a policy to increase density in an area by increasing demand for floor space there with special features will not be reflected in the modeling projections, except to the extent that they affect travel impedance.

Assessing Land Use Strategies with MEPLAN and TRANUS

Can the MEPLAN and TRANUS modeling systems evaluate the impact of the strategy (e.g., higher density, mixed use) on trips and/or VMT?

As discussed in Chapter 3, both land use models and transportation models formulate the modeling areas as a set of contiguous zones. Note that because these models integrate land use and transportation analyses, both systems are represented by the same zones.

The spatial resolution of the zones is limited by a number of factors. Required data, especially employment (place-of-work) by economic sector, may be available only at a coarse level of resolution. An additional factor pertains to the calibration procedure. Although the procedure used in for these models is not dependent on statistical procedures, like DRAM/EMPAL, it is still the case that matching available data tends to be easier when data are more aggregated.

In practice land use analysis zones in these models are typically significantly larger than census tracts. For example, a recent TRANUS application to Sacramento, CA, used zones with an average size of more than 10 square kilometers. The average size of an urban census tract is about 2 square kilometers. With an analysis zone of census tract size it may be possible to detect, for example, increased density within 0.5 to 1.0 kilometers of a transit station, or transit corridor (strategies 5 and 6). However, for larger zones, such microscale development characteristics may not be distinguishable. A similar problem pertains to the representation of mixed use and/or pedestrian friendly site design (strategies 1 and 3). Because the objective of such designs are to encourage pedestrian traffic modes, they are necessarily specified at a very fine spatial scale corresponding to walking distances. But even if a variety of land uses are projected to occur in a large zone, without further analysis it is not clear how to determine whether the configuration constitutes mixed land use development with respect to encouragement of walking. Increased density at larger spatial scales, such as infill/densification and strong downtowns (strategies 1 and 2), may be represented, but the mixed use characteristics will still be obscure.

If the mixed use character of an area could be quantified, it could be added to the formulation of the mode choice equations in the travel portion of the model, assuming that its impact could be calibrated with historical data, i.e., that sufficient data are available to determine the relationship between mixed use development and travel mode selection.

As noted above, transportation zones are the same size as the land use zones. The larger they are, the more trips will be intrazonal. Because the transport model of TRANUS ignores intrazonal trips, the use of large zones may be a particularly significant limitation for analysis of the impact of high density and mixed use on encouraging mode shifts (e.g., walking and bicycling) for short trips.

Thus, if the modeling system is implemented with analysis zones that are larger than census tracts, as is typically the case, the target land use strategies will not be well represented within the modeling framework.

6 CONCLUSIONS AND RECOMMENDATIONS

One of the objectives of this study was to assess the ability of currently available land use models and integrated land use-transportation models to evaluate the impact of land use policies and strategies designed to reduce travel demand. The identified land use strategies included:

- high density development at various spatial scales
- mixed use development at various spatial scales
- infrastructure modifications

The impact of each of these strategies on travel demand can be evaluated with an appropriate travel demand model, which includes adequate representation of all the travel modes of interest and how they are selected by travelers.

However, a land use model or an integrated land use-transportation model is required to quantify to what extent specific land use policies can achieve the objectives of increased density and mixed use, since government cannot directly accomplish these objectives. Such a model is not required to evaluate the effectiveness of policies to achieve infrastructure modifications, which are generally accomplished by direct government action.

Three types of policies were identified for encouraging higher density and mixed land use:

- zoning;
- non-monetary incentives; and
- monetary incentives.

Three modeling systems that incorporate algorithms to project the spatial distribution of land use activities, and that are generally commercially available to planning agencies, were identified:

- DRAM/EMPAL, part of ITLUP
- MEPLAN
- TRANUS

Land Use Strategies

A significant potential limitation for all of these models, with respect to their ability to evaluate the impact of the land use strategies of high density and mixed use on travel demand pertains to the size of analysis zones. Each is typically applied with zone definitions that are significantly larger than census tracts, which tend to be in the size range of 2 square kilometers in urban areas. The use of large zones is driven primarily by two factors: (1) availability of input data, especially with respect to place of employment; and (2) difficulty in achieving successful calibration with a disaggregated configuration. The TRANUS model can be configured with nested zones, so that spatial resolution is finer in targeted areas, but even the nested zones are typically the size of several census tracts.

If the mixed use character of an area could be quantified, it could be added to the formulation of the mode choice equations in the travel portion of the models, assuming that its impact could be calibrated with historical data, i.e., that sufficient data are available to determine the relationship between mixed use development and travel mode selection.

Land Use Policies

Zoning

The impact of zoning policies on development decisions cannot be well-represented in DRAM/EMPAL. Development densities could be imposed, but only after land use activities had been allocated to zones. Similarly, zoning for mixed use development could be represented only by constraints to be checked for violation after land use allocations are made.

MEPLAN and TRANUS, in contrast, include floor space zoning restrictions in the spatial choice formulation, as well as development costs. The former could represent development density at the zonal level. Specified development costs presumably could be modified in accordance with density regulations to influence development decisions. However, because these parameters can be specified only at the zonal level, the size of zones may limit the ability of these models to evaluate policies designed to influence development at small spatial scales, e.g., near a transit stop.

Similarly at the zonal level, zoning policies that encourage mixed development might be represented in MEPLAN and TRANUS by manipulation of floor space zoning maxima for various activities among zones. However, because the model formulation treats new development for the various activities independently, the extent to which land uses mix at the micro-scale level (i.e., smaller than zones) cannot be addressed.

Monetary Incentives

DRAM/EMPAL has no direct representation of costs in employment or residential location decisions. Thus, monetary incentives to guide land use development cannot be represented.

In MEPLAN and TRANUS development of new floor space is projected, in part, on the basis of development costs. Therefore, policies that offer monetary incentives to developers to build in targeted zones or at specified minimum densities could be represented in the models in terms of decreased development costs. Again, these can only be specified at the zonal level, so that the size of the zones is an important consideration for evaluating policies that target small scale development characteristics.

Non-monetary incentives/disincentives

Some non-monetary incentives, such as reduced parking requirements or accelerated permit processing, are designed to lower costs for developers. Therefore, developers responses would be similar to those for monetary incentives, which cannot be represented in the DRAM/EMPAL models, but can be represented in the MEPLAN and TRANUS models.

For all three models, an incentive such as an infrastructure upgrade that resulted in reduced travel impedance, suitably estimated with a travel demand model, could be represented in the models and influence locational choice. Similarly, parking restrictions can be represented as increased travel impedance within the models. However, the spatial scale of application of these policies may be significantly smaller than the scale of the analysis zones, so that detection of any impact would be difficult.

Note that for all the models, the limited number of independent variables used to make projections may lead to underestimates of the full impact of some infrastructure improvements, such as a pedestrian-friendly environment attracting additional households to an area. All the formulations consider composite travel impedance (time and out-of pocket costs) and past attractivity in residential location choice. In addition MEPLAN and TRANUS consider costs of floor space. However, an increase in the attractiveness of a zone due to addition of special features like pedestrian-friendly environments, will not be captured by any of the models unless an attractiveness factor for the special feature is added to the formulation and its impact determined by calibration with historical data. That is, sufficient data must be available to quantify the relationship between the presence of the special feature and the attractiveness of the area. Otherwise, a policy to increase density in an area by increasing demand for floor space there with special features will not in general be reflected in the modeling projections, except to the extent that they affect travel impedance.

Recommendations For Future Work

The following improvements to standard land use and transportation modeling tools would facilitate their use in evaluating the impact of the strategies and policies discussed in Chapter 2.

- Development of data and procedures to allow land use analysis at fine spatial resolutions, such as census tracts;
- Development of data to determine the relationship between special land use features of interest (e.g., pedestrian-friendly environments, mixed land use development), and neighborhood attractiveness;
- Development of data and procedures to allow incorporation of pedestrian and bicycle modes, as well as public transit, into travel demand models;
- Development of data to determine the relationship between mixed use development and travel mode selection;
- Development of data and procedures to allow incorporation of trip chaining into travel demand models;
- Development of data and procedures to allow incorporation of temporal choice into travel demand models.

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