MAKING THE LAND USE, TRANSPORTATION, AIR QUALITY CONNECTION - MODELING PRACTICES, VOLUME 1

CAMBRIDGE SYSTEMATICS, INC. WITH HAGUE CONSULTING GROUP

OCTOBER 1991

Funding provided by: The Energy Foundation, Surdna Foundation, Inc., The Nathan Cummings Foundation, The Metropolitan Service District (Portland, Oregon), The United States Environmental Protection Agency

ABSTRACT

"Making the Land Use, Transportation, Air Quality Connection" (LUTRAQ) is a national demonstration project to develop methodologies for creating and evaluating alternative land use patterns and design standards that will:

- reduce dependence on automotive travel;
- increase mobility for all segments of society;
- minimize negative environmental impacts, particularly those on air quality;
- reduce energy consumption; and
- foster a strong sense of community character.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

"Making the Land Use, Transportation, Air Quality Connection" (LUTRAQ) is a national demonstration project to develop methodologies for creating and evaluating alternative land use patterns and design standards that will:

- reduce dependence on automotive travel;
- increase mobility for all segments of society;
- minimize negative environmental impacts, particularly those on air quality;
- reduce energy consumption; and
- foster a strong sense of community character.

Using a proposed $200 million bypass freeway around the Portland, Oregon metropolitan region as a case study, LUTRAQ will (1) identify alternative land use development patterns that reduce travel demand and increase the use of alternative travel modes, and (2) develop reliable transportation modeling procedures that forecast the travel behavior associated with these alternative land use patterns.

The LUTRAQ project contains six primary tasks:

Task A. Analyze Current Model Limitations

In Task A, the project team will (1) identify the international state-of-the-art of integrated land use/transportation modeling; (2) determine current modeling practices in U.S. metropolitan areas; and (3) evaluate the modeling system in place for the LUTRAQ study area.

Task B. Analyze the Base Case

The project team will establish current land use and transportation opportunities and constraints in the study area.

Task C. Develop the LUTRAQ Alternative Package

The project team will establish a package of alternatives to freeway construction, containing three primary elements: (1) alterations in area land uses, densities, and development design standards, (2) expansions in transit facilities and services, and selected existing collector/arterial systems, and (3) changes in land use and non-land use policies, including those related to transportation demand management.

Task D. Modify the Models

The team will improve the modeling system in the study area to assure accurate measurement of the alternative package developed in Task C.

Task E. Test the Alternatives

Using the modeling improvements from Task D, the team will analyze a no-action alternative, a freeway alternative, and the LUTRAQ alternative package (developed in Task C) for their effects on congestion, land use, air quality, energy consumption, quality of life, public finances, and user costs.

Task F. Implement the LQ Alternative Package

The team will prepare a set of recommended actions to implement the elements of the alternative developed in Task C.

Work products from the LUTRAQ project include a separate volume devoted to each task, plus a final report and technical appendix.

Volume	Title	Authors
1	Modeling Practices	Cambridge Systematics, Inc. and Hague Consulting Group
2	Existing Conditions	Cambridge Systematics, Inc. and Calthorpe Associates
3	Description of Alternatives	Calthorpe Associates and Cambridge Systematics, Inc.
4	Model Modifications	Cambridge Systematics, Inc.
5	Analysis of Alternatives	Cambridge Systematics, Inc. and Calthorpe Associates
6	Implementation	Cambridge Systematics, Inc. and Calthorpe Associates
7	Final Report	Cambridge Systematics, Inc. and Calthorpe Associates
8	Technical Appendix	Cambridge Systematics, Inc. and Calthorpe Associates

Volume List

SUMMARY

This volume contains three chapters. The first is a summary of currently available interactive transportation and land use modeling systems. The second is a survey of the state of the practice in transportation and land use forecasting at the metropolitan level in the United States today. The third is a description and analysis of the transportation and land use forecasting system used in the Portland, Oregon metropolitan area.

Interactive transportation and land use models replicate the ways in which people and businesses make their locational decisions and the ways in which these decisions affect traffic congestion. We know that commuting time and cost influence the choice of a place to live, and that business location decisions are affected by the extent of traffic congestion, as well as by the location of employees' residences. Interactive models forecast the ways in which these numerous decisions in a metropolitan area affect one another over time.

In our review of such modeling systems available internationally, we identified fourteen commercially available packages in the United States, Europe, South America, Asia and Australia. The first chapter describes the theoretical basis, operating characteristics and recent applications of the most widely used of these modeling systems. We identify three systems which are the best developed and potentially most useful packages for the kinds of issues and applications common in U.S. metropolitan areas today.

In our second chapter, we conclude that **land use forecasting procedures have essentially remained unchanged in the majority of our major metropolitan areas for nearly twenty years**. During this same period less than a dozen agencies and regions have used land use modeling techniques to predict the locations of households and jobs. Among these few regions which have undertaken more sophisticated means of land use forecasting, however, only two have implemented fully the tools to predict the ways in which congestion influences land use, while land use patterns simultaneously influence congestion. Both of these systems have deficiencies which need correction.

None of the regions have enhanced their models sufficiently to reflect the understandings we have today regarding the determinants of individuals' travel decisions. Clearly one of these influences is the built environment itself. The ways in which urban design improvements, land use mix and density affect the number of trips, length of trips and mode choice of travelers is not included in regional travel demand forecasting models used anywhere in the United States today.

In the third chapter, we review the travel demand forecasting system used in the Portland, Oregon metropolitan area. We conclude that, **while the Portland modeling system contains a large number of state-of-the-art enhancements, it shares the widely prevalent weakness of regional models in its inability to simulate: (1) the ways in which people's choices of where to work or locate a business are determined by congestion and travel costs, and (2) the ways in which designs oriented to pedestrians, bicycles and transit can influence decisions about where and how to travel**.

Taken as a whole, these three chapters acknowledge a widely-known but rarely discussed conclusion that travel demand forecasting in the United States has remained unchanged for too long. **The tools in use today are not reliable for solving the urban and regional transportation problems faced by our metropolitan areas**. The models are unable to simulate accurately the likely consequences of the kinds of public policies and programs needed to solve congestion problems, or, more fundamentally, the responses of residents to the transportation choices and options they face everyday.

OVERVIEW

The standard travel demand forecasting system consists of four stages: trip generation, trip distribution, model choice and trip assignment. This system has remained relatively static over the last fifteen years. In most regions, only incremental improvements have been made to regional travel demand models. Selected areas, such as San Francisco, Portland, and Seattle, have taken important initiatives but the majority of urban areas have done little new work.

The significant model system improvements during this period have been implemented outside the United States. These advances, taken together with current U.S. thinking, provide evidence of what the next generation of travel demand forecasting systems should look like.

The orientation of most U.S. planners has been to the construction of major new radial highway and transit systems. This had led modelers to develop tools which are designed to forecast traffic volumes on specific road segments.

A new range of policies, however, is attracting the interest of planners and policy-makers. Sensitivity to these policies will drive the next round of model improvements. These policies include the following:

- congestion management,
- improved air quality,
- reduced energy consumption,
- highway and parking pricing, and
- urban development and growth management.

The data on which many current model systems are based are relatively old. Significant changes are occurring, such as multiple-worker households, increasing auto ownership, flexible work schedules, increased leisure time and a steady increase in the average age of drivers. As a result, travel demand relationships developed 15-20 years ago are no longer valid today.

New travel surveys need to be collected, covering a broader range of data and permitting more detailed analysis than has been done to date. By combining this data with 1990 census data, which will be available on a geographically coded basis, planners can and will be undertaking new regional travel forecasts in the early 1990's. Their accuracy and usefulness will be limited, however, since they will be based on model structures which are inadequate. The inadequacies affect both the reliability of the forecasts themselves, and their usefulness in forecasting the likely effects of the kinds of policies mentioned above.

Thus there is an imperative to enhance and improve the practice of travel demand forecasting and the model systems on which these forecasts rely. The needed improvements include the following:

1. **Disaggregated models**. Model systems which rely more on the behavior of individuals, and less on their aggregate behavior in arbitrary neighborhoods ("zones") should come into greater use. Travel behavior decisions should be modeled individually.

A broader range of travel choices should be forecast than is typical today, including alternative modes such as walking, bicycling, and/or linked mode trips. Attitudes or stated preferences of individuals should be explicitly modeled. In the past, travel models have relied on quantifiable measurements of variables such as travel time and cost. Emerging modeling techniques can now easily handle a person's preference for fixed rail over bus transit, for example. Such preference models should be given increasing use.

2. **A decrease in standardization**. Microcomputer-based travel demand systems will increase in popularity. While some model systems will become more sophisticated, there also will be a greater reliance on approaches that require less data collection and are more user-friendly. Users will be able to customize their models, using established model theories such as demand elasticities, pivot point application of disaggregate logic models, and spreadsheets. Rather than using the standard Urban Transportation Planning System (UTPS) model, travel demand modelers will assemble models from component parts for particular objectives.

3. **Land use/transportation models**. Land use models should be integrated with transportation models. The effects of congestion (among other things) on location decisions are understood and are incorporated into commercially available, international land use models of the kinds described in Chapter 1. Most U.S. models, however, are not equipped to simulate these effects.

Today, land use models are just coming into use in the United States. As the following chapter indicates, there are several such models available. Some do not incorporate well the effects of land prices, rents, and space availability on locational decisions. Yet it is well known that housing costs and commercial rents are key determinants of current location decisions in metropolitan areas. In the future, both the number and variety of interactive land use/transportation models should increase, as should their use.

4. Geographic Information Systems. Future models will evolve into database management systems. Efforts are underway today to integrate travel demand systems with geographic information systems (GIS). Eventually, all transportation and land use data should be stored in a format with appropriate geographic coding. This will permit a variety of geographic displays to be easily produced. GIS should become the means by which data should be not only displayed, but also stored, managed and analyzed.

These four areas represent the directions in which improvements in travel demand forecasting are likely to occur in the 1990's. They represent the leading edge of today's state-of-the-art, rather than hoped for results from fundamental research. The challenge is to translate these developments into tomorrow's "best" practice, and then into standard practice.

The principal obstacle to these innovations is government financial support. Model system advancements have taken place in Europe, Australia and elsewhere, in part because of strong central government funding and influence. In contrast, there has been a decrease in U.S. transportation research funding at the federal level in recent years, along with a major delegation of authority to state and local government. Many state and local transportation agencies lack both the technical expertise and the funding to develop newer, more sophisticated transportation modeling systems. The authors hope that the LUTRAQ project strengthens the case for the implementation of such systems nationwide.

A role for federal agencies in this effort is imperative. State agencies must share this responsibility, along with regional organizations.

The necessary basic research has been done. The challenge is to fund projects designed to demonstrate the practical value of these innovations, and then to educate constituencies on the benefits of implementing the new demonstration systems. The pioneering efforts of the agencies and foundations supporting this project will be, we hope, the first of many in this regard.

CHAPTER 1: ALTERNATIVE LAND USE MODELS

Introduction

This chapter summarizes current information on the principal commercially available modeling systems which simulate the interaction between land use patterns and transport systems. In particular, it focuses on the representation of the land use components of the various systems, in the sense of the different types of land use that each system identifies, and the explicit relationships that are assumed between land use, accessibility, and other economic factors.

The information presented here draws on published and unpublished work from twelve groups of modelers in eight countries. The models, and their countries of origin, are listed on Table 1; on the table we also indicate which of those models are actually available (perhaps in modified form) for possible use

Table 1. Models Reviewed for the Report

Name	Country of Origin	Available
1. TOPAZ	Australia	Yes[1]
2. MEP	U.K.	Yes
3. ITLUP	U.S.A.	Yes
4. LILT	U.K.	No
5. AMERSFOORT	Netherlands	No
6. CALUTAS	Japan	No
7. DORTMUND	Germany	No
8. OSAKA	Japan	No
9. SALOC	Sweden	No
10. MEPLAN[2]	U.K.	Yes
11. TRANUS	Venezuela	Yes
12. TRACKS	Australia	Yes
13. TRANSTEP	Australia	Yes
14. TOPMET	Australia	Yes[1]

[1] *Involvement of the author agency would be required.*
[2] *MEPLAN is a later version of MEP, both developed by Marcial Echenique and Partners.*

in the LUTRAQ study.

The first nine models were selected for participation in the ISGLUTI study (International Study Group on Land Use/Transport Interaction), set up by the Transport and Road Research Laboratory (the principal U.K. government transport research establishment) in 1981. Their findings were reported in 1988, and contain detailed reviews of the model systems together with much useful background information on transportation/land use modeling (Webster et al, 1988). This study extended to a detailed comparison of model performance, but unfortunately lacked the resources to allow all the modeling groups to participate. In the end, only DORTMUND, LILT and MEP completed all the tests. As indicated on the table, of these fourteen, only MEP, ITLUP, MEPLAN (an extended micro-computer version of MMP), TRANUS, TRACKS and TRANSTEP are available for purchase/lease; however, there are mature plans to market commercial versions of TOPAZ and TOPMET, so these will be regarded as potentially available also.

Table 2 sets out means of contacting all of the agencies involved. Telephone and FAX numbers should be preceded by the appropriate international code.

This chapter is divided into four sections. Following this short introduction, we present a general overview of the models involved, drawing heavily on the material in Webster et al (1988). This is followed by a more detailed appreciation of the commercially available models, including operational and financial aspects. Finally, we give a short summary of findings.

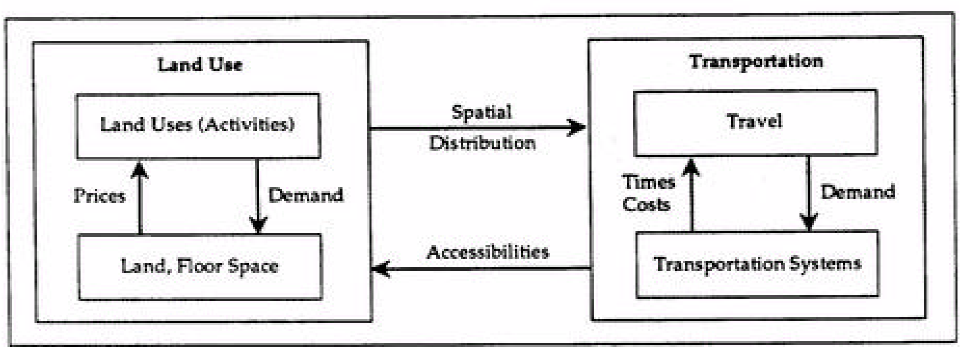
Table 2. Model Systems and Author Agencies

Model	Company	Address	Contact	Phone (FAX)
TOPAZ TOPMET	SCIRO	Graham Road Highett Victoria 3190 Australia	J. Brotchie	35562211 (35533005)
MEP MEPLAN	Echenique & Partners	49-51 High Street Trumpington Cambridge U.K.	I. Williams	223840704 (223840384)
ITLUP	S.H. Putman Associates	Dept. of City and Regional Planning, Univ. of Pennsylvania Philadelphia 19104 USA	S.H. Putman	2158986207 (2155732034)
TRANUS	Modelistica Rickaby	Regency Court 220 Upper Fifth Milton Keynes UK	P. Rickaby	908679520 (908666002)
TRACKS	Gabites Porter Ltd.	P.O. Box 13078 Christchurch New Zealand	G. Smith	3669871 (3669870)
TRANSTEP	R.J. Nairn & Partners	M.T. I.A. House 214 Northbourne Av, Braddon, ACT Australia	R. Nairn	62497644 (62573032)

Overview of Transportation/Land Use Models: The Base in Neoxy

Figure 1 sets out in schematic form the basic concepts and linkages involved in most transportation and

Figure 1. The Integrated Land Use-Transportation Model



land use models.

Given that the objective is to predict the way in which different sub-areas (or zones) in the study area will tend to attract different land uses (or activities, such as residential occupation, retail shopping, industry, education), the figure provides an illustration of the interrelationship that can arise between the activities undertaken in the zones and the transportation systems that link the zones.

Two distinct 'Subsystems' are identified, being:

1. the Land Use sub-system, within which, for a given level of accessibility associated with a given transportation sub-system, market forces work to divide out available space between the different activities, and

2. the Transportation sub-system, within which, for a given activity/land use pattern and transportation network, a resulting pattern of movements is predicted. In turn this leads to a new prediction of the accessibility of each zone with respect to the others, which can be taken as a new input for the land use sub-system.

For example, consider the sequence of events following the introduction of a new link in the transportation network (a new highway, or metro line, or even a dedicated bicycle path). The ability to travel faster, or cheaper, or simply by a preferred means-of-travel affects the zones served by the new facility, increasing or decreasing the attractiveness of those zones as a location to visit to conduct any particular activity.

Subsequently, as the locational attractiveness of a given zone increases, so do the demands it places on the transportation system to bring the flows of people (workers, shoppers) and/or goods from surrounding areas. Accordingly, the average cost (or time) of travel to the area increases also. This effect tends to reduce the attractiveness of the area, as does the tendency for rental values to increase. Ultimately, if neither of these effects is sufficient to halt the growth in activity in the area, capacity restrictions of the maximum available space must take over to limit growth.

In fact, the systems aim to emulate a large number of interrelationships between different groups of people, with different objectives, each responding in its own way to the behavior of the other groups and to any other changing circumstances.

Within the 'land use' box, the major players are businesspersons/entrepreneurs, private households buying homes, land-owners (who are sometimes private households selling homes) and planners. The first two groups compete with themselves and each other for the 'best' locations; 'accessibility' is a factor involved. Landlords use this competition to adjust rents to their own advantage (up or down) and planners intervene with regulations of various sorts.

Within the 'transportation' box, the major players are private travelers and transportation planners (including system operators). Members of the first group compete with each other to find the 'best' locations for out-of-home activities (work, shop, education, etc.), judging potential destinations on the basis of the cost of reaching the destination and the quantity and quality of the opportunities available there. Transportation operators (public or private) use this competition to pursue their own objectives. For example, public authorities generally expend public money to minimize wasted time and cost in travel; their options include construction of new facilities and setting fare levels. Private transportation companies, of course, are mainly concerned with maximizing their own profits.

The arrow from the 'transportation' box to the 'Land Use' box establishes one direction of influence; from the processes in the 'Transportation' box, accessibilities change. This affects the desirability of locations in the 'land use' box.

The arrow in the other direction completes the circle; from the processes in the land use box, the pattern of spatial distribution (the quantities and qualities of opportunities in given locations) changes. This affects the desirability of potential destinations in the 'transportation' box.

Whether these effects occur simultaneously, or sequentially in some order over time, is indeterminate. Equally, whether an equilibrium point is possible at all, let alone reached in any period, is uncertain. Practical model applications must find ways to estimate all the explicit interrelationships they cover, and also ways to apply the relationships within a sequential framework. The most common approach is to assume that the transportation system comes into an equilibrium within the current period given Current land use; future land use develops more slowly, and is influenced by (and hence analyzed in relation to) the transportation characteristics of previous periods.

To this extent, the overall model can remain permanently out-of-equilibrium through any forecast period, even though the transportation sub-model is assumed to stabilize.

Of course, many factors other than land use affect travel demand, and many factors other than accessibility and rents affect land use patterns. The degree of emphasis given to sub-components of the system varies according to the circumstances of the area being modeled. In practical terms, this has led to the emergence of two major identifiable groups of model systems.

One of these groups contains the systems ITLUP, TRANSTEP and TRACKS. In these systems, little or no attention is paid to the internal economics of the land market, in terms of the ways in which differential attractiveness for various land uses affects rental values and finally ultimate land use mix. This feature greatly simplifies the models, both for data requirements and for operational complexity.

MEPLAN, MEP and TRANUS, on the other hand, focus directly on competition and resulting rents as a means to confront available supply of land with the various demands of the different activities. This increases the potential power of the models, but at the cost of a high burden of data needs and computational difficulty.

A second difference between the two groups concerns the calculation of the total size of the workforce and the population. In the 'ITLUP' group, both must be given to the system by the user. In the MEPLAN' group, the user specifies only employment in the 'basic' (non-service) sector. This latter set of models then infers both service employment and total population consistent with this 'basic' employment.

In the field of (almost) commercially available packages, TOPAZ and TOPMET (a derivative of TOPAZ) have a somewhat different orientation, at least in their most widely, used forms. Where the other systems attempt to predict what will happen, TOPAZ and TOPMET attempt to determine what should happen, in the sense of which patterns of design (land use, or even building design) best match some pre-specified objective of the system user. This is a feature which may prove of interest in this study.

A final comment concerns the numbers of travel modes distinguished by the model systems. In principle, this is undefined, in the sense that the basic models deal with ,accessibilities which can be calculated in a general sense for multiple modes. In practice, it has not been usual to deal with non-mechanized modes, such as walking or bicycling. An extension of the MEPLAN model incorporating non-mechanized modes is now under test in The Netherlands.

Commercially Available Systems

This report identifies seven commercial packages which might be of interest to the LUTRAQ project.

As we have seen these seven fall into three district groups. Below, we deal in turn with the ITLUP group, the MEPLAN group, and TOPAZ/TOPMET.

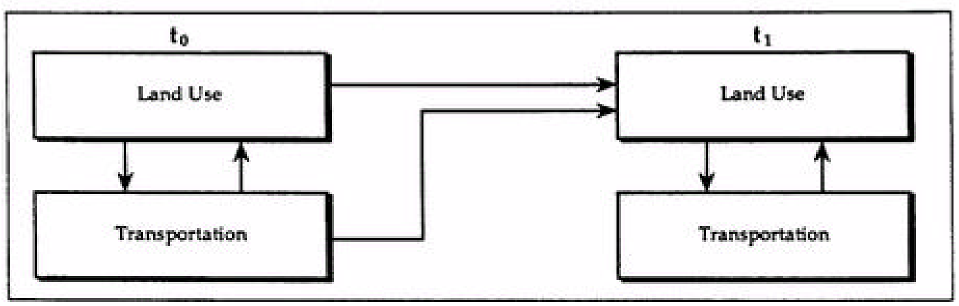
The ITLUP Group

This group contains the three packages ITLUP, TRACKS and TRANSTEP.

ITLUP

General Description. Professor Putman, of the United States developed the ITLLT as an addition to the standard four-step transportation model (as exemplified by the UTPS system). Essentially, ITLLJP extends the standard model to deal with the location of employment and the location of households, organized in such a way that the future land use patterns are affected by both previous land use patterns

Figure 2. ITLUP: Land Use – Transportation Interaction in Time

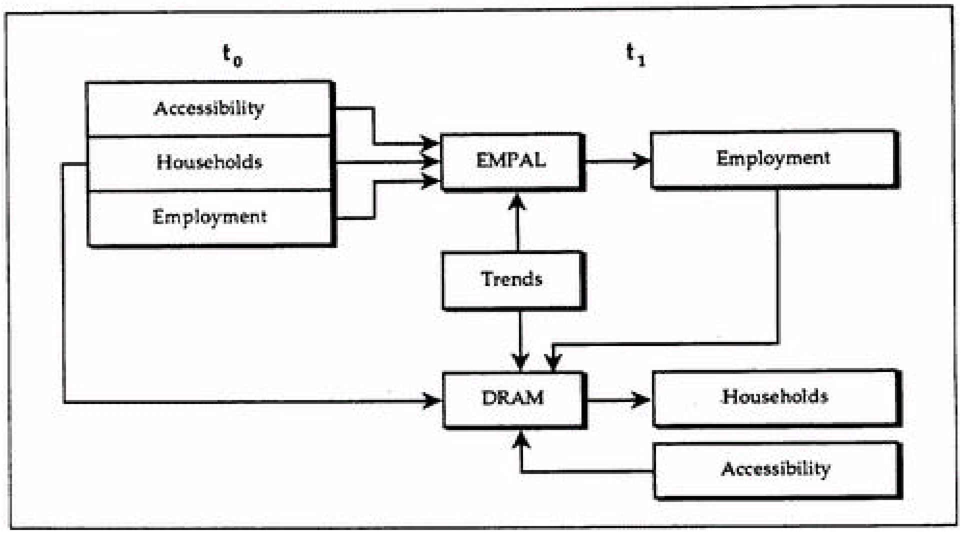


and previous levels of accessibility (see Figure 2).

The land use oriented part of ITLLTP consists of three submodels. The first sub-model, EMPAL, allocates employment to zones. In order to do so, it uses exogenous forecasts of total employment per employment type (basic and non basic), together with zone-specific levels and trends in employment growth and zone-specific measures of zonal accessibility to the workforce.

Next, the residential allocation sub-model DRAM forecasts the future location of households given this distribution of employment. This part also uses measures of attractiveness (including accessibility) of the zones. The workings of DRAM and EMPAL are illustrated in Figure 3.

Figure 3. ITLUP: General Working of EMPAL and DRAM



A third submodel (actually within DRAM), LANCON, calculates land consumption in a future year, using base year information and exogenous forecasts.

DRAM also generates (mechanized mode, 2 types) trips for three purposes, namely home-to-work, home-to-shop and work-to-shop.

ITLUP also offers mode-split, distribution and assignment modules; these are of standard form, and are not relevant for our present purposes.

Representation of Land-Use. As with all the other land use/ transportation systems reviewed here, ITLUP works on the basis of a user-specified zone system. A substantial amount of exogenous information is needed in order to establish zonal land use in base and forecast years.

Relationship Between Transportation and Land Use. Equations I(l) to I(7) (taken from Putman 1991), specify the two sub-models; both are based on singly-constrained spatial-interaction model formulations, incorporating multivariate attractiveness functions.

$P_{i,t-1}$ = total population of zone i at time t-1

$\lambda^k, \alpha^k, \beta^k, a^k, b^k$ = empirically derived parameters

DRAM

$$N_i^n = \sum_j Q_j^n B_i^n W_i^n c_{ij}^{\alpha^n} \qquad I(4)$$

where

$$Q_j^n = \sum_k a_{k,n} E_j^k \qquad I(5)$$

and

$$B_i^n = \left[\sum_i W_i^n c_{ij}^{\alpha^n}\right]^{-1} \qquad I(6)$$

and

$$W_i^n = \left[L_i^v\right]^{q^n} \left[x_i\right]^{r^n} \left[L_i^r\right]^{s^n} \prod_{n'} \left[\left[1 + N_i^{n'} \Big/ \sum_n N_i^n\right]^{b^n_{n'}}\right] \qquad I(7)$$

where

N_i^n = households of type n residing in zone i

L_i^v = vacant developable land in zone i

X_i = 1.0 plus the percentage of developable land already developed in zone i

L_i^r = residential land in zone i

$a_{k,n}$ = (regional) coefficient of type n households per type k employee

$\alpha^n, \beta^n, q^n, r^n, s^n, b^n_{n'}$ = empirically derived parameters

Note that in DRAM all variables have the same time subscript.

The key equations are I(l) and I(4). Equation I(l) shows that potential employment in zone j occupying workers from zone i is calculated on the basis of the previous population of zone i, the previous attractiveness of zone j (in terms of jobs and area), and the current disutility of travel between the zones. In some sense, then, this allows a representation of the workers' choice of workplace location that we placed within the transportation 'box' in Figure 1. Forecast total employment at zone j is then taken as an interpolation between previous employment and the sum of these potential levels over

Input Requirements. To represent the base situation, ITLUP needs data on employment for each distinct employment 'sector' the forecaster wishes to distinguish (3 to 5 are usual; exact definitions depend on the nature of the area under study) and per zone, population per zone and per category (four income groups are usual), land allocation per zone and per activity, the transportation network (links, speeds, capacities) of the area and travel times per mode.

For calibration, ITLUP requires data on employment per sector and per zone for the period subsequent to the base year.

To produce forecasts, ITLUP requires the following exogenous future data: employment per sector, regional population per category, trips per person and per purpose, and network data (links, speeds, capacities).

Forecasts are done in five-year steps. Model output of a run for one forecast year becomes the input for the next run.

Calibration Requirements. ITLUP contains a sub-program, CALIB, which returns estimates of the unknown parameters in DRAM and ENIPAL.

It is understood that the calibration of the LANCON sub-model is also simply and automatically performed with a regression package.

Hence, calibration requirements may be judged to be reasonably light. The major effort is allocated to data collection.

Output. ITL represents output on a zonal level. Land use quantities presented are employment per sector, population per income group and working/non working category, land allocation per activity, and vacant land. Also, ITLUP produces information on trips per origin/destination and purpose, trips per purpose, income group and mode, average travel time per origin/destination per mode, and travel energy per purpose per social/car ownership group and mode. Also, it has an option to produce air pollution information. ITLUP produces no planning and economic indicators. Basically, information is presented in tables on a disaggregate level. Also, totals and statistical details on a regional basis are presented. Graphics modules are available with ITLUP to produce maps and networks.

Extent of Validation. ITLUP has been validated in the sense that model runs have generated predictions which have been compared with the actual situation five years later. 1980 data on Kansas City were used as input to the model, and the results of one run (= 5 years) were compared to the actual situation in the region in 1985. Identical exercises were carried out in Houston and Los Angeles. Summaries of the results have been made available to the consultants only in the form of overall goodness of fit at a zonal level, a measure which can be difficult to interpret without further information. However, on the basis of these measures the five-year forecasts have been close to the actual outcome in each case.

Operational Requirements. ITLLTP is programmed in FORTRAN. It runs on a mainframe, and for a 300 zone system requires approximately 1000 Kbytes of memory and takes about 200 CPU seconds to run.

Cost. The software is not for sale separately. An agency or firm may hire S.H. Putman Associates to consult on a model application project. Projects may be specified so that after the programs are installed and tested on the chent's hardware, the client receives a perpetual non-exclusive license for the software. Ownership of the software and related documentation is retained by S.H. Putman Associates.

A typical one-year project is $30,000. Generally, the cost to an agency for training, installation and technical advice, including a software license ranges from $30,000 to $90,000.

Current and Recent Applications. The ITLUP model system has been applied in several metropolitan areas. The development of the system started in 1971 using data for the San Francisco region.

Since then, it has been applied to urban regions such as Houston (client: Houston-Galveston Area Council) and Dallas (client: North Central Texas Council of Governments) in the US and Taipei in Taiwan (client: Transportation Planning Board of the Ministry of Communications).

Also, it has been used in the less urbanized region of Sarajevo, Yugoslavia (client: Institut za Arhitekturu, Urbanizam, i Prostomo Planiranje).

TRANSTEP and TRACKS

TRANSTEP and TRACKS are commercially available packages in current use in Australia and the Far East. General information and program specifications have been received for the companies involved (and are included in the Resource Material in the Annex). For our purposes, these two packages are dominated by ITLUP, in the sense that their land use components are (on the evidence available) inferior to ITLUP. In fact they are based on the ITLUP approach, but are less well developed.

Of interest, however, is the extent of use. The TRACKS material quotes use in some 20 cities (mainly on traffic and transportation studies) and TRANSTEP claims 31 users, with applications in 9 countries.

The MEPLAN Group

This group consists of the systems MEPLAN, MEP and TRANUS. In fact, we shall restrict ourselves to MEPLAN and TRANLJS; MEP is an early, mainframe-based application of the system now sold under the MEPLAN name.

MEPLAN

General Description. The MEPLAN-model has been developed by Marcial Echenique & Partners over a period of years, drawing on research conducted in collaboration with the group who were later to produce TRANUS.

The approach uses Economic Base theory (North, 1955), which essentially allows it to generate the study area population and employment endogenously, given forecasts of 'basic' employment.

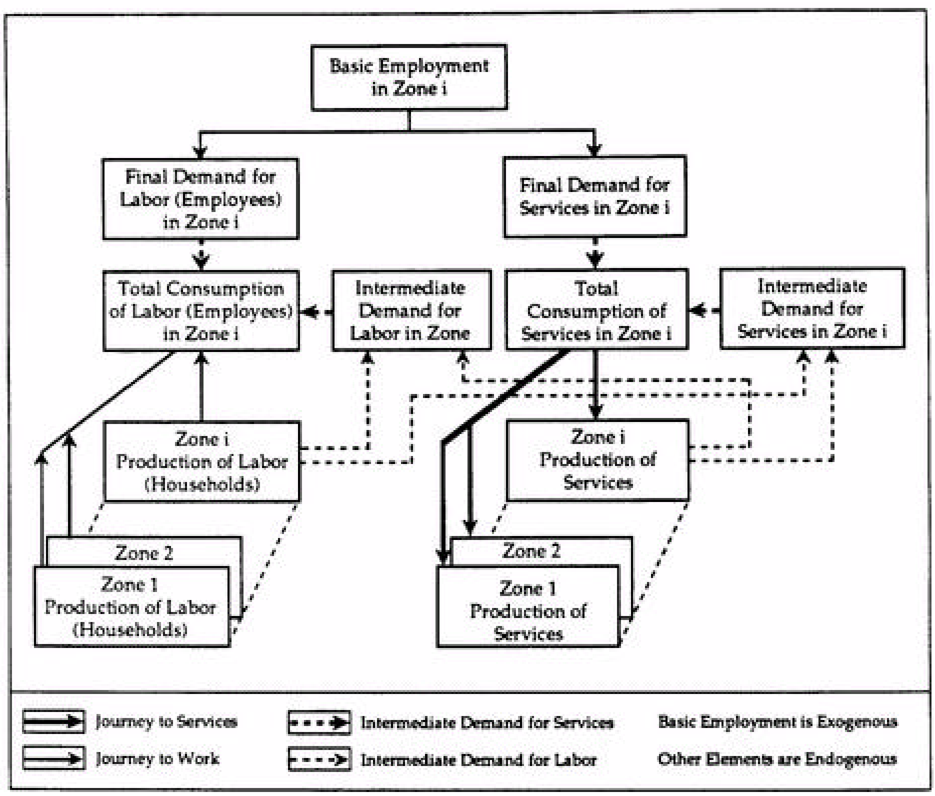
The second feature of the system is that it relies heavily on input/output modeling techniques. Input/output matrices are built up in terms of activity-to-activity flows, where there are 9 activity types. Activities 1-4 are household activities (persons residing); 5, 6 and 7 cover secondary and tertiary employment, and 8 and 9 cover the (input) primary employment sectors.

The input-output tables then specify how much of each activity is required as input to generate one unit of a given activity in a region as output. For example, jobs in a primary industry require a labor force, and thus also require the presence of households to generate the labor force; in turn, the households place demands on services such as shops and schools, which in turn involves employment in service sectors.

Thus, based on information on (regional) employment in basic sectors (such as manufacturing industries, ports, CBD'S) and on an estimate (derived from base year information) of the number of households that provide one basic worker, the system calculates the number of 'basic-worker' households in the region. These households are then allocated to residential zones on the basis of a singly-constrained gravity-model calibrated on base year data.

These households, after having been allocated to zones, must be supported by services such as shops and schools. The model calculates the required number of jobs in the service sector and as a final step determines the number of households that are involved in fulfilling these jobs. These households bring in more people, who need to be provided with services, so that more service jobs are generated, more service workers including their households move into the region, etc. The model avoids possible over-population in a region by adjusting the rent of floor space in a zone to the demand in each iteration, and

Figure 4. Spatial Input-Output Model for a Multi-Zone Example (MEPLAN)



by respecting an absolute maximum amount of available floor space. Figure 4 illustrates the process.

The transportation section of the model splits travel demand in public (bus and rail) and private transportation, calculates travel times and costs and assigns trips to routes. Congestion is modeled by restricting the capacity of a link. Travel time and costs are used in the utility maximization of location-choice in a next period.

Models

Representation of Land-Use. Most variables needed to model land use are endogenously determined by the MEPLAN-model itself. All it needs is a forecast of basic employment in a region and a set of coefficients of the input/output matrix used to express relationships between activities in zones.

The zonal population is divided by income into four household groups.

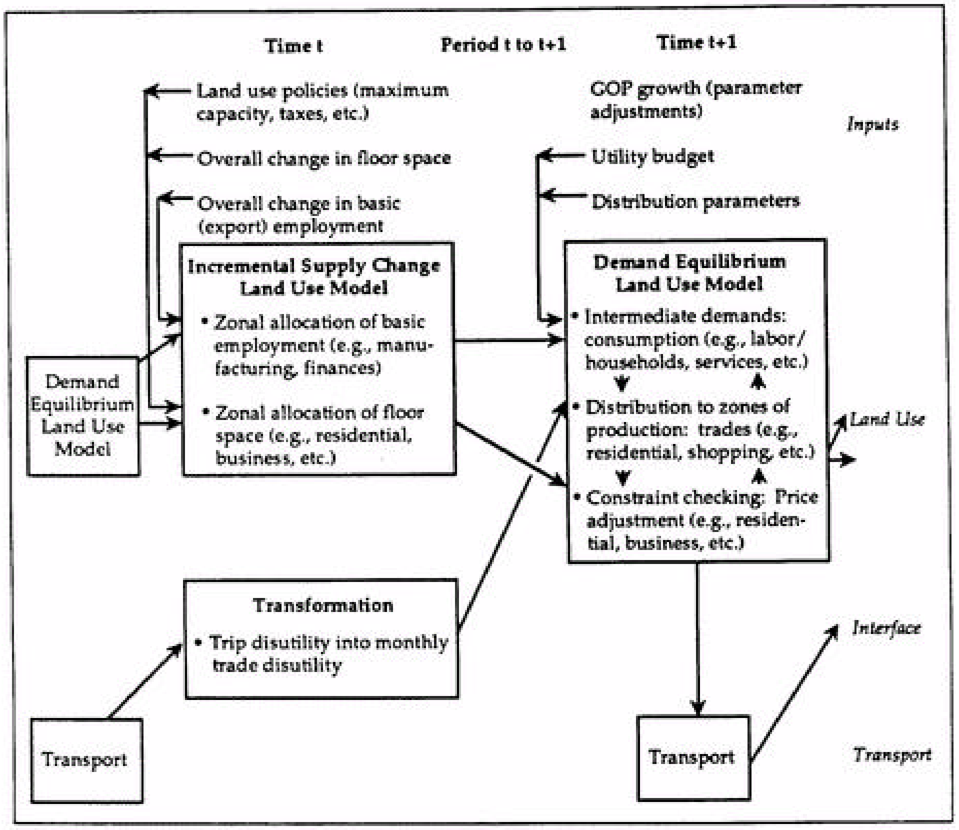
Relationship Between Transportation and Land-Use. Equations M(l) to M(l 3), taken from the ISGLUTI report, specify the MEP application and broadly specify MEPLAN. Together, these equations perform the same role as the equations I(l) to I(7), with the additional transportation-related feature that they determine trip generations M(5).

Over and above this feature, the system also generates:

3. Floor space made available for each activity in each zone M(2) (i.e. the actions of the businessmen (and women) in creating buildings);
4. Estimates of the demand for floor space for each unit of each type of activity in each zone M(4) (at given rent and income for that activity); this reflects decisions made by private individuals and companies;
5. Demand for other goods and services per unit of each activity in each zone M(6) (given rent and income); this also reflects decisions made by private individuals and companies;
6. Land demand M(7), simply related to floor space demand;
7. Total demand for floor space in each zone M(12), at given rent levels, income and accessibility; and
8. Like, rent adjustment in each zone M(13) at given levels of rent, income and accessibility; this represents the likely reaction of landowners in pursuit of profit.

Figure 5 illustrates how these relationships operate over time.

Figure 5. Land Use Model Through Time (MEPLAN)



Floor space location depends on profitability and available land:

$$F_{sit} = F_{sit-1} + A^F \Delta^F_{st} \left[r_{it-1} - c_{it}\right]^{\beta^F} \left[L_{it} - F_{sit-1}\right]^{\beta^F} \qquad M(2)$$

where

X_{sit} = amount of activity s in zone i in time period t

ΔX_{st} = total increment of activity s in period t: this is exogenously determined for basic sectors (s =8,9)

y_{nit-1} = nth attribute of zone i in time period t-1, such as available land, previous basic employment, etc.

F_{sit} = floor space used for activity s in zone i in time period t

ΔF_{st} = total increment of floor space in time period t

r_{it-1} = floor space rent in zone i in the previous time period t-1

c_{it} = cost of building a unit of floor space

L_{it} = maximum permitted floor space in zone i by zoning regulations during time period t

$\alpha_{sn};\beta^{r};\beta^{F}$ = parameters

Equilibrium Model of Land Use

Demand for activity s from zone j is estimated via input-output coefficients between that activity (s = 1 .... 7) and all other activities (r = 1 .... 9):

$$Y_{sj} = \sum_{r} a_{rx} X_{rj} \qquad M(3)$$

Equations estimating demand for floor space, travel and other goods and services are utility maximizing subject to an income constraint:

Floor space demand per unit of activity (residential activities, s = 1 .... 4) in zone 1 is:

$$f_{si} = f_s^* + \xi_{sf}/r_i \left[I_s - r_i f_s^* - c_{si} n_s^* - c_z z_s^* \right] \qquad M(4)$$

Trip generation demand per unit of activity (residential activities, s = 1 .... 4) in zone 1 is:

$$n_{si} = n_s^* + \xi_{sn}/c_{si} \left[I_s - r_i f_s^* - c_{si} n_s^* - c_z z_s^* \right] \qquad M(5)$$

Demand for other goods and services per unit of activity (residential activities, s = 1 .... 4) in zone is is:

$$z_{si} = z_s^* + \xi_{sf}/z \left[I_s - r_i f_s^* - c_{si} n_s^* - c_z z_s^* \right] \qquad M(6)$$

Land demand is calculated directly from floor space, since the plot ratio is fixed in each zone for the period:

$$l_{si} = f_{si} / p_i \qquad M(7)$$

Similar, but simpler equations are used for non-residential activities (s = 5,6,7).

From these demands a locational utility for each activity (s = 1 .... 7) in zone i is calculated as:

$$u_{si} = \left[l_{si} - l_s^*\right]^{\delta_s^l} \left[f_{si} - f_s^*\right]^{\delta_s^f} \left[n_{si} - n_s^*\right]^{\delta_s^n} \left[z_{si} - z_s^*\right]^{\delta_s^z} \qquad M(8)$$

Attractivity for location of activity (s = 1 .... 7):

$$W_{sijt} = \exp\left[-\gamma_s t_{sijt-1}\right] \prod_{n \in s} \left[X_{nit-1}\right]^{\eta_{sn}} \qquad M(9)$$

Hence activities (s = 1 .... 7) can be located as a function of the various flows:

$$Z_{sij} = Y_{sj} F_i^s U_{si} W_{sij} B_{sj} \qquad M(10)$$

whence:

Total activity of types located in i:

$$X_{si} = \sum_j Z_{sij} \qquad M(11)$$

Total demand for floor space:

$$F_i^D = \sum_s f_{si} X_{si} \qquad (s = 1 \ .... \ 5) \qquad M(12)$$

and floor space rents are adjusted by the ratio of floor space demand to supply:

$$r_{it} = r_{it-1} \left[F_{it}^D / F_{it}^S\right] \qquad M(13)$$

where

a_{rs} = input-output coefficient demand for activity r by activity s (r = 1 .... 7; s = 1 .... 9)

f_s^* = minimum requirement of floor space by unit of activity s

r_i = floor space rent in zone 1

n_s^* = minimum requirement of trip generation by unit of activity s

c_{si} = zonal trip cost for activity s in zone i

z_s^* = minimum requirement of other goods and services by unit of activity s

c_z = cost of other goods and services

l_{si} = land area per unit of activity s in zone i

l_s = land area per unit floor space for activity s

P_i = plot ratio in zone 1

I_s = income of unit of activity s

u_{si} = locational utility of activity s in zone i

Z_{sij} = location of activity s in zone i to satisfy the demand in zone j

W_{sijt} = attractivity for location in zone i of activity s which is determined in zone j in time period t

t_{sijt-1} = travel time between zones i and j in previous time period t-1

X_{nit-1} = amount of activities located in the previous time period

F_i^S = supply (S) of floor space in zone i

γ_s; η_{sn} = parameters

γ_{nt-1}^B; A^F = scaling factors

Input Requirements. To represent the base situation, MEPLAN needs data on employment per sector and per zone, population per zone and per category (four income groups), land allocation per zone and per activity, floor space per zone and per activity, the transportation network (links, speeds, capacities) of the area and a trip matrix for purposes other than work or shopping. Also elasticities of household consumption of

MEPLAN: Basic equations (from Webster et al. 1988)

Location of activities depends on two approaches. Total basic employment (in activity categories s = 8 and 9) and total floor space are provided exogenously as increments in each time period and allocated to the zones endogenously in the incremental models. Other activities, residential (s = 1 .... 4) and secondary and tertiary employment (s = 5,6,7) are estimated via input-output coefficients and allocated to zones in the equilibrium model of land use.

Incremental Models

Basic activity location (s = 8,9) depends on zonal attributes:

Incremental Models

Basic activity location (s = 8,9) depends on zonal attributes:

$$X_{sit} = X_{sit-1} + \Delta X_{st} \left[\sum_{n} \alpha_{sn} \, Y_{nit-1} \, A^{B}_{nt-1} \right] \qquad M(1)$$

Access to an up-to-date set of input-output tables is also needed.

For calibration, MEPLAN needs data on land allocation and floor space (both per zone and per activity) in the period subsequent to the base. Finally, it needs a work trip matrix per mode and per social group for the base period.

In order to make forecasts, MEPLAN requires the following exogenous future data: employment per sector for the basic sector, the level of land readjustment and network data (links, speeds, capacities).

Calibration Requirements. MEPLAN combines two calibration techniques. For the linear functions it uses least squares estimation; the non-linear functions are estimated by standard maximum likelihood routines.

Output. MEPLAN presents output on zonal level. Land use quantities presented are employment per sector, population per income group, households per social and car-ownership group, land allocation per activity, vacant land and floor space per activity. Also, MEPLAN produces information on trips and average travel time per origin/ destination per income group, and the amount of travel energy used per mode. Air pollution is optional. Finally, MEPLAN produces some planning and economic indicators. It is possible to get aggregate tables from MEPLAN.

A major problem with the type of output described above is that tables are hard to interpret for most users. Therefore, some graphics modules are available with MEPLAN to make results visible in diagrams, maps and even three-dimensional pictures.

Extent of Validation. The commonly accepted definition of 'validation' refers to the process of checking the forecasts produced by the model against the observations at a later date, using observed values for all exogenous variables between both time points. To our knowledge, MEPLAN has not been validated in this sense.

Actual forecasts (rather than the model structure) have been 'validated' in the application of the model to Bilbao and Sao Paulo, though the intervals of time between the forecasts and the surveys have been very short (five years). The Sao Paulo results showed good aggregate forecasts, especially in the transportation sectors, though zonal forecasts were less satisfactory. The forecasts in the Bilbao study were mostly fairly accurate.

Operational Requirements. MEPLAN is programmed in FORTRAN. The mainframe version tested in the ISGLLM study required 450 Kbytes of memory and took up to 300 CPU seconds to run for an approximately 50 zone system.

The microcomputer version, operating on a powerful machine with appropriate specifications (especially a fast disk) would be capable of operating with zone systems of up to 300 zones.

Cost. The MEPLAN model consists of four modules. They carry out the following tasks:

- LUS Regional economic/urban land use models
- TAS Freight/passenger transportation model including both public and private transportation

- TRED Interface between LUS and TAS
- EVALE Evaluation of land use and transportation effects.

The modules can be purchased separately. Prices at 5 October, 1990 (in U.S. dollars) are:

The modules can be purchased separately. Prices at 5 October, 1990 (in U.S. dollars) are:

MEPLAN Modules	IBM-PC Compatible	Other
LUS	$ 7,500	$15,000
TAS	6,500	13,000
TRED	3,200	6,500
EVAL	4,250	8,500
Complete system (20% discount)	$17,000	$34,000

Simultaneous purchase of any two modules attracts a 5% discount.

Graphics Modules	IBM-PC Compatible
TASG	$2,500
EVALG	2,500
DIGITIZE	1,300
Complete system (20% discount)	5,000
Maintenance	
First year	free
Second and third years	15% of purchase price
Subsequent years	subject to negotiation
Educational discount	50%
Educational discount (four-zone model)	85%

All prices are in US $ at an exchange rate of $1.7=1 pound sterling, and are net of VAT, local taxes, import duty etc.

Current and Recent Applications. As has already been mentioned, MEPLAN has been applied to the cities of Bilbao (client: municipality of Bilbao) and Sao Paulo (client: local authorities).

Other applications are the area of Cambridgeshire (private clients) and the city of San Sebastian (client: Basque Government and Diputacion Foral de Guipuzcoa).

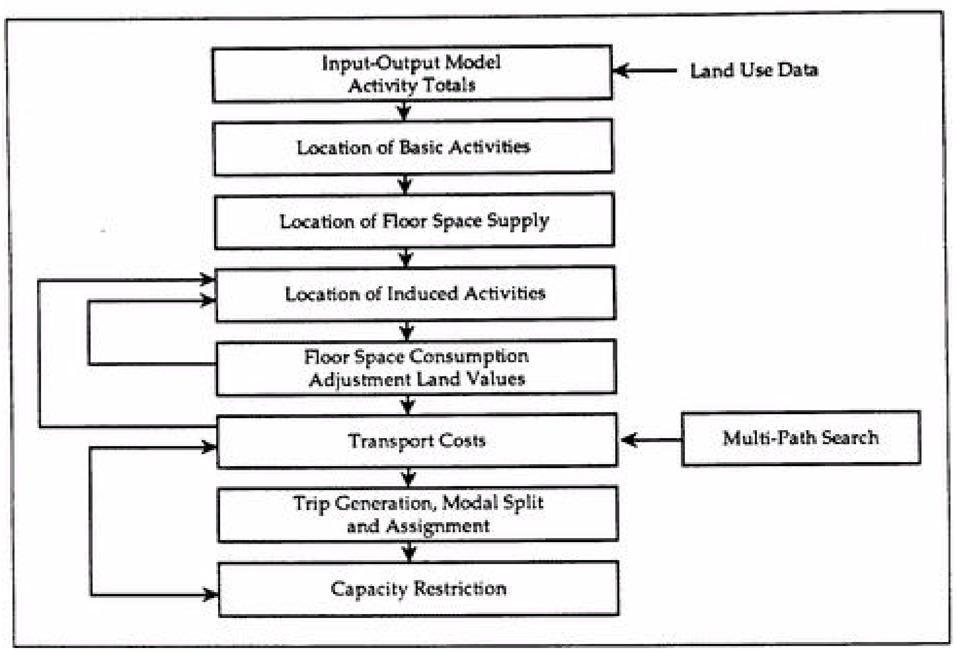
Recently, it has been combined with the Dutch National Model (travel model) and applied to the Amsterdam region (client: Dienst Verkeerskunde van de Rijkswaterstaat). This process is still in the development stage.

Promotional material and a summary of recent applications are provided in the background material in the Annex.

TRANUS

General Description. The TRANUS-model has been developed by the Venezuelan company MODELISNCA. Like MEPLAN, it makes explicit assumptions about demand and supply relationships in the land market and uses Economic Base methods to generate regional employment and population. It also uses concepts of individual utility maximization to generate demand for activity location which is eventually reconciled with the supply of both floor space and transportation access through rent adjustments and the feed-back of transportation system delays. Figure 6 illustrates the

Figure 6. Calculation Sequence Used by TRANUS (MEPLAN)



system.

The transportation section splits the trips generated in modes, using a hierarchical structure in which a high-level choice between public and private transportation is divided between public transportation sub-modes.

Representation of Land Use. The land use model uses erogenous information on basic employment, and generates information about household types and other types of employment in a way entirely analogous to MEPLAN.

Further details about the specification of necessary data inputs is not available at this time; we may suppose it is similar to MEPLAN.

Relationship Between Transportation and Land-Use. Changes in land use have an immediate effect on transportation. This is modeled through matrices; a land use pattern generates functional flow-matrices per socioeconomic sector. These matrices are translated into trip matrices per origin-destination pair by the transportation section of the model.

A change in transportation changes land use in the following period. This is based on the reasonable assumption that activities do not react to the introduction of a new transportation facility or the growth of congestion immediately, but after a period of time has elapsed.

Input Requirements. The model input consists of the total basic employment in a region, location of activities in a previous time period, current land use policy, transportation costs for a previous time period and a set of technical coefficients. The other variables are determined endogenously.

Calibration Requirements. Several calibration programs are included in TRANUS. Optimal parameters for the utility functions of the land use section (logic-models) are estimated using the method called 'Search by Golden Section'. There are separate programs to estimate the parameters for the transportation section.

Output. TRANUS has been developed to evaluate the effect of policies. The output exists of histograms comparing variables such as employment, population, floor space and land values. The histograms will show the differences between two sets of results, to show where growth has located if the two runs correspond to two time periods of the same scenario, or to show the effects of policies if the runs correspond to two scenarios in the same time period. Correlations can also be asked for.

Extent of Validation. Validation has been carried out on existing data, as with ITLUP. Application of the model to urban land use planning on the island of Curacao included a check-run for the base year 1981 and future year 1985. Policies as carried out in 1981 as well as validation-data for 1985 were known. The TRANUS model is quoted to have proved to give useful results.

Operational Requirements. TRANUS Version 3.1 runs on any IBM-PC XT, or AT, or other fully compatible machine. It requires 850 Kbytes and takes about 15 minutes to run a 30 zone application on a 8 MHz machine. The improved Version 4.0 (to appear in 1991) All require at least an IBM-PC model AT or other fully compatible machine.

Cost. The TRAN-LJS model Version 3.1 costs $ 4,250, including documentation in English or Spanish and one year of user support. The commercial price of the forthcoming upgrade from Version 3.1 to Version 4.0 will be $ 850. Export sales of TRANUS outside the UK are not subject to Value Added Tax.

Current and Recent Applications. In order to evaluate urban land use planning, TRANUS has been applied to the island of Curacao and the city of La Victoria (Venezuela). Both projects were carried out for local authorities.

Regional land use planning has been the object of studies in Venezuela (Caracas-La Guaira Motorway; Central Railway system).

Also, the model has been applied in a study concerning urban transportation planning applications in the city of Caracas and to model the relationship between the spatial organization of society and its use of energy in the area of eastern central England (Center for Configurational Studies, The Open University, UK).

TOPAZ/TOPMET

General Description. The TOPAZ-model was developed by Drs. Brotchie, Sharpe and Toakley from the Division of Building Research of the Commonwealth Scientific and Industrial Research Organization, Australia. It is an optimizing program, maximizing a user-specified objective function subject to constraints.

In its first and classical applications, the program was used to generate patterns of activity locations which would be maximally environment-friendly, in the sense of leading to low .values of pollution emission, energy consumption and so on.

The assumptions within the model were that travel demand could be forecast from spatial active locations using entropnr-maximizing principles (to predict travel patterns conditional on land use and transportation configurations). Welfare economics principles were also used (to set an objective function in terms of maximizing social benefit). However, the major feature of the program is that it is a powerful optimizing tool for complex objective functions subject to certain restraints. The program can be used on problems with very different scales, ranging from regional land use configurations to the organization of individual buildings (where the problems of interaction become three-dimensional). TOPMET is a development of TOPAZ which has been particularly tailored to the more detailed level of planning.

The first step in the TOPAZ model is to allocate activities to the zones. Both employment and housing are distributed such that a weighted sum of the costs of the urban infrastructure and the incurred transportation costs are minimized. Next, trips are generated, split into two modes (road and rail) and assigned to the network. Travel time and cost are calculated. Also, costs involved in either congestion or maintaining the network in order to meet the demand are calculated, and so are the related land prices. Finally, the data are aggregated to the urban or regional level.

The outcome of one run serves as input for the next, as is the case with all of the model systems reviewed. Several time periods can be handled either sequentially or simultaneously. In that way, 'a model-run takes past decisions into account; also, it can anticipate future decisions. This is especially useful in regions where land use and transportation plans are known on beforehand.

Representation of Land Use. TOPAZ needs exogenous forecast of both employment per sector and total population for the entire region. The model itself allocates these to zones.

During a model run, only location variables change. Composition of population and housing market are fixed - demand and supply are considered static.

In allocating activities to zones, TOPAZ uses attributes of work trips as attraction factors. Also, it uses attributes of zones. There is no land price estimation, but the objective function to be optimized contains infrastructure costs.

Land allocation is optimized by maximizing the net benefit (less costs) to be obtained from interaction (travel) and land use, i.e.:

$$\text{Maximize} \sum_{r} \sum_{t} U\left[X_{rit}\right] - \sum_{r} \sum_{i} \sum_{s} \sum_{j} \sum_{m} \sum_{t} T_{rsijmt}\, d_{tjmt}\, x^{t}_{rsijmt} \qquad T(1)$$

$$+ \sum_{r} \sum_{i} \sum_{t} X_{rit}\, x^{E}_{rit}$$

subject to the following constraints:

Zone capacity constraint (i.e., total activity, accumulated over all time periods, cannot occupy more than available area):

$$\sum_{r} \sum_{t} \left[X_{rit} \big/ j_r\right] \le L_i \qquad T(2)$$

Demand clearing constraint:

$$\sum_{i} X_{rit} = X_{rt} \qquad \text{(for all r and t)} \qquad T(3)$$

Non-negative constraint on activity allocation:

$$X_{rit} \ge 0 \qquad \text{(for all r, i, t)} \qquad T(4)$$

where

X_{rt} = total activity of type r to be located in time period t

X_{rit} = a portion of total activity X_{rt} of type r to be allocated to zone i during period t

$U(X_{rit})$ = total merit (usually benefits less costs) of allocating a portion X_{rit} of activity r to zone i in period t

T_{rsijmt} = amount of interaction between the portion of new plus existing activity r in zone i and the portion of new plus existing activity s in zone j for the mth mode of interaction during period t.

Since TOPAZ is a general optimal location mechanism this need not necessarily refer to travel, but in the ISCLUTI usage the interaction refers to numbers of trips and is estimated using a doubly-constrained entropy-maximizing equation of the form:

$$T_{rsijmt} = A_{rit}\ B_{sjt}\ O_{rit}\ D_{sjt}\ f\left[x^{t}_{rsijmt}\right] \qquad T(5)$$

in which the function of net travel benefits, $f(x^{t}_{rsijmt})$ splits trips between public and private modes using a standard logit relationship.

O_{ri} = number of trips generated by activity r in zone i in time period t

D_{sj} = number of trips attracted by activity s in zone j in time period t

A_{rit}: B_{sjt} = flow balancing factors

d_{ijmt} = distance of travel path (or travel time) between zones i and j for the mth mode of interaction during time period t

x^{t}_{rsijmt} = benefit less cost of a unit of (transportation) interaction along a unit distance of path

between zones i and d

x^{E}_{rit} = benefit less cost of establishing and operating (E) a unit of activity r in zone i during period t

j_r = density per unit area of activity r

L_i = area available for all activities in zone i

Relationship Between Transportation and Land Use. In TOPAZ, a change in land use has a major effect on trip patterns and a minor effect on modal split in the same time period. Also, a feed-back to land use itself from the transportation system can occur in the same time period.

Equations T(1) to T(5) specify the system.

In the other direction, there are immediate effects of transportation cost on land use factors. Only the location factors are adjusted during a run. This is most obvious in employment, housing stock and population location. Industrial and retail location, as well as land allocation, are less influenced by a change in transportation cost. In the same time period, there also is a feed-back to transportation demand from the land use mechanism.

Generally, TOPAZ does not distinguish between population, housing and employment categories, though with some effort the model can be adapted in a disaggregate fashion.

It is also possible for linkages to be allowed backward to a previous period, since the allocation of land use in one period may achieve a more beneficial configuration if it takes account of future event. TOPAZ permits this anticipation of future changes because it seeks a completely general optimum configuration.

Input Requirements. To represent the base situation, TOPAZ needs data on employment (per zone), population total (or per zone), land allocation per zone and per activity, the transportation network (links, speeds, capacities), a trip matrix, travel times per mode and trip lengths.

In order to produce forecasts, TOPAZ requires data on employment per sector and per zone, land allocation per activity, constraints on land use, the transportation network (links, speeds, capacities), car ownership and establishment costs of activities. Future travel times per mode and trip lengths may be input to the model, but may also be calculated endogenously.

Calibration Requirements. The land use model of TOPAZ by its nature needs no calibration: it is the solution to the problem, chosen to minimize weighted costs, where the weights are chosen by the planner. These weights may vary in order to compare sensitivities.

The trip-distribution part of the model is calibrated with standard techniques, to maximize a likelihood criterion based on observed trip patterns.

Output. The land use part of TOPAZ produces output on zonal level on employment per sector, total population, land allocation per activity, vacant land and the location of houses in the new situation. The transportation section generates output on trips per mode and per journey type, travel energy used per origin and purpose and (optional) air pollution as a consequence of travel.

Finally, the model produces some planning indicators (accessibility per zone per trip type and per mode) and economic indicators (developers cost, travel costs per mode and per trip type and marginal cost of incrementing activity levels).

Output is presented in tables, (color) graphics and line drawings.

Extent of Validation. TOPAZ has not been validated. The reason for this is straight forward: TOPAZ is an optimizing model, and there is no reason to expect that the optimum land use configurations will correspond with actual development. Therefore, the model has to be considered a tool for the planner to assist in decision making.

Operational Requirements. A major advantage of TOPAZ is that it has very modest computer requirements. The program was written in FORTRAN, it runs on a microcomputer, and for a 40 zone system it takes only between 5 and 30 CPU-seconds and requires 30 to 120 Kbytes of memory.

Cost. TOPAZ is currently only operating in experimental mode. It is planned to restore and upgrade it to a commercial version at a price of around $2,500 per copy. The present version runs on a large 386 or 486 MSDOS-machine but is not up to commercial speed yet. If necessary, CSIRO may be willing to run TOPAZ for a client in the mean time.

Current and Recent Applications. TOPAZ was originally developed in 1970 to study the future development of the Melbourne region, Australia (client: Melbourne and Metropolitan Board of Works).

After this, studies in several other urban areas followed (Blacksburg Virginia, client: local authorities; Gosford-Wyong Australia, client: State Planning Authority of New South Wales; Darwin Australia, client: National Capital Development Commission).

Also, it has been applied to regional areas (New River Valley, Australia; mainly academic purposes) and on a smaller scale to arrange buildings on a university campus (Virginia Polytechnic Institute and

State University) or rooms in and location of hospitals (Sydney, Australia; client: authorities of the City Western Metropolitan Hospital Region).

Additional Issues

The framework used above describes the major model systems, and the research done to date to evaluate them, leaving the following questions unresolved:

- How well can each of the models be used to evaluate the effect of urban design policies on locational decisions? To the extent that these policies have effects not measured in travel savings or land rents, can their benefits be forecast?
- How well can each of the models work if zones are as small as the 15-20 acre pedestrian pocket which may be developed in Portland or elsewhere?
- How well or differently does each model respond to changes in transportation policies generally? What level of sensitivity does each display to the kinds of policies to be considered in the LUTRAQ study, such as pricing policies, alternative mode choices, and a variety of demand management strategies?

These questions will be answered in part by the LUTRAQ study itself, and in part by other studies which undoubtedly will occur. The importance of these issues will insure that the tools are carefully tested and enhanced as required.

Final Comments

This chapter reports on a major body of work that has been conducted by a number of different agencies around the world. Methods and even objectives have differed between the different groups.

The ISGLUTI team has made a considerable contribution to the dissemination of knowledge about this subject. Further material has been supplied by agencies around the world, documenting models not available to ISGLLM.

This is an area of planning which is absolutely necessary to address to make progress with many typical transportation planning studies; it is also an area of the science which is in its infancy, not merely because the subject is intrinsically so difficult to approach, but because of the wide range of academic disciplines involved.

The major conclusion from this review of available models is that the choice between existing systems depends very largely on time and money resources (the MEPLAN group being very expensive in terms of data requirements and calibration time) and what is actually required in the way of output (the ITLUP group giving no insight into the development of rents or the land market). Further, if the objective is to specify land use patterns, rather than predict them, only TOPAZ/ TOPMET offers a direct possibility .

The major value of the more complex systems may well be in the insights gained by the analyst in the data collection, analysis and operation stages. If insufficient funds or time exists to reap these benefits, more direct means (e.g. market research methods to determine likely commercial and private demand) might be considered as a supplement to the simpler approaches.

From the material gathered, and in the time allowed for consideration of the potential benefits of each system, we have reached several conclusions.

9. Of the model systems examined, ITLLJP, MEPLAN and TOPAZ/TOPMET are the three best developed and potentially most useful packages.
10. Of these, we recommend the application of the ITLLJP package for the LUTRAQ project. Because of the complexity of calibration, verification and application of any interactive land use model, the availability of Dr. Putman, the model developer, for this project is highly advantageous.
11. The time-scale of LUTRAQ is not compatible with the acquisition, calibration and application of either MEPLAN or TOPAZ/TOPMET; they require large resources of data, manpower and, particularly, experience to turn into useful planning tools in a given application.
12. In the longer run, the ideas within MEPLAN could contribute to an understanding of the possible trends in land values and land uses in Portland; the ideas in TOPAZ/TOPMET could add to the evaluation of effectiveness of specific planning regulations and policies in meeting regional objectives.

References

Webster, F.V., P.H. Bly and N.J. Paulley, "Urban Land Use and Transportation Interaction," Avebury 1988.

North, D.C., 1955, Location Theory and Regional Economic Growth, Journal of Political Economy, Vol. 63, p. 243.

Putman, S.H., 1991, DRAM/EMPAL ITLLJP General Description.

CHAPTER 2: SURVEY OF CURRENT PRACTICE

Introduction

This chapter contains an overview of the current state of the practice in travel demand modeling. To what degree do leading transportation planning agencies incorporate land use data or modeling procedures into their travel demand forecasts? To what extent do current models allow for the inevitable interaction between transportation and land use over time, and the effects of this interaction on the location and overall levels of travel demand? This chapter addresses these questions.

Methodology

To gather the needed information on the state of current land use and transportation modeling practice, the consultants undertook a survey of transportation planners in the twenty largest Metropolitan Statistical Areas (MSAS) in the United States today. In addition, the consultants surveyed planners in two other metropolitan areas known to be at the leading, edge of domestic practice in the use of land use data.

The objective in identifying candidate regions for inclusion in this survey was to develop a sample which we believe to be broadly representative of best practice trends. While it was important to be able to describe specific practices in major regions, it was not essential that the sample be either complete or statistically significant.

The survey process consisted of two phases. In the first phase, the consultants contacted one or more individuals identified as most knowledgeable about transportation modeling practices in their respective regions. The consultants posed a series of questions to the interviewees to gather information on several broad topics:

- current land use forecasting procedures,
- current transportation modeling practice,
- current relevant public policy issues,
- current air quality issues, and
- current modeling needs.

On each topic, the interviewers posed a series of open and closed ended questions, through a telephone interview of approximately thirty minutes duration. Interviewees were given ample opportunities to expand upon their key ideas.

At the close of the interview, local planners agreed to send additional information to the consultants concerning their models and applications. In addition the consultants arranged to transmit a one page matrix to the interviewees. The matrix contained a series of variables frequently used in transportation models. The interviewees were asked to identify the ways in which each variable affects travel predictions for their region.. The interviewees indicated all variables which were involved in a direct relationship with key output of their model. Interviewees completed the matrix and returned it to the consultants in a timely fashion.

Of the twenty-two regions selected for inclusion in this sample survey, consultants were able to complete questionnaires for seventeen regions. Detailed matrices were returned for sixteen regional models.

The reader should note that all the individuals interviewed were in the position of representing facts and opinions concerning large and diverse regions. The consultants have conducted limited verification of the information given by interviewees. Despite these cautions, the researchers believe that the findings described below accurately represent the state of the practice. New information, or responses from additional regions, will certainly serve to enrich but not to change fundamentally the findings and conclusions.

With responses in hand from a majority of the regions selected for inclusion in this study, the consultants have found an ample base of information from which to draw conclusions. The sections which follow contain summaries of the principal findings.

Findings and Conclusions

This section summarizes the principal findings and conclusions on major topics covered in the research. In Appendix A, the reader will find a narrative summary of the major findings from each region interviewed. Appendix B contains a copy of the questionnaire.

The Use of Land Use Data

The regions surveyed for this study can be grouped into four broad categories by the way in which they Use land use data in their travel demand forecasting.

The first group contains a plurality of respondents to our questionnaire (see Table 3). While they represent 42% of our sample, these agencies in fact typify the vast majority of regions using travel demand models today, because the survey design involved a nearly 100% sample from the three other

Table 3. Use of Land Use Data in Travel Demand Forecasts

Traditional	Innovative	Transitional	Integrated
Metropolitan Transportation Council (New York)	Houston-Galveston Area Council	Orange County, CA Governments (Seattle)	Puget Sound Council of Governments
Chicago Area Transportation Study	Mid-America Regional Council (Kansas City)	Southern California Association of Governments (Los Angeles)	Association of Bay Area Governments/Metropolitan Transportation Commision (Oakland)
Southeastern Michigan Council of Governments (Detroit)	San Diego Association of Governments	Southwestern Pennsylvania Regional Planning Commission (Pittsburgh)	
Washington (DC) Area Council of Governments	North Central Texas Council of Governments (Dallas)	Metropolitan Area Planning Council (Boston)	
Dade County, FL	Middlesex-Somerset-Mercer Regional Council (Princeton, NJ)		
East-West Gateway Regional Council of Governments (St. Louis)			
Maricopa Association of Governments (Phoenix)			
Metro (Twin Cities, MN)			

Source: Cambridge Systematics, Inc.

groups named.

Transportation planners in these regions essentially use land data today the same way they did a decade or two ago. Planners in these regions have no models which develop an explicit land use forecast. Instead they use one or another regional forecasts for population and employment as a surrogate.

The job of assigning households, individuals, and employees to analysis zones smaller than the area for which forecasts were made is achieved essentially by a consensus among planners and, on occasion, public officials. The techniques for doing so varies from region to region.

While all the regions surveyed use a formal model for generating regional forecasts of households, population, and employment, (with some using more than one model for this purpose), none of the "traditionalists" use any formal model to allocate land uses among analysis zones. Furthermore, their transportation models do not have any means of showing how future transportation systems impact the distribution of land use. Rather, land use data is incorporated as an input to the first step in the traditional four step transportation planning process. The only means by which any feedback occurs from transportation to land use is through the updating of regional transportation forecasts and plans, which occurs in regions at five or ten year intervals.

Planners in these regions have no means for assessing the land use impacts of incremental changes in the transportation system. Nor do they have any means to assess the effects of other public policies (such as demand management) on regional land use.

A second set of regions use a land use forecasting model to allocate land uses to small area zones in a systematic, quantitative manner, rather than in the relatively more judgmental way which characterizes traditional, consensus-oriented allocation procedures. These forecasts are used in the traditional manner, as input to the four-step process. Among the regions using this "innovative" approach are Councils of Government in Houston-Galveston, San Diego, Kansas City and Dallas.

All of these regions use the DRAM/EMPAL model for this purpose. DRAM/EMPAL, as fully described in the first chapter of this volume, is a model which allocates several types of residences and employees to individual analysis zones using travel impedances (time and/or money) as the principal determinant of location choice.

One organization, the Middlesex-Somerset-Mercer-Regional Council (New Jersey), has developed enhancements to the traditional four-step process, without the use of any land use model, which take into account the effects of alternative development patterns, and their urban design characteristics, on trip generation. The work involved a sketch plan modeling technique (a simplified representation of the transportation network). The technique is described in the subsection ("Specific Forecasting Techniques") which follows.

A third set of regions is involved in a transition from "traditional" modeling practice to a more advanced and/or interactive set of models and procedures. This "transitional" group is in the process of selecting, calibrating, or validating a formal land use modeling system whose forecasts they will incorporate eventually into their travel demand forecasting.

In the Pittsburgh, PA region, the Southwestern Pennsylvania RPC is investigating the feasibility of developing its own land use forecasting model. This work is in its theoretical stages. It does not appear to be leading to the integration of land use and transportation models, but rather to the development of a fixed land use forecasting system. All of the other respondents who fall into this second category are installing DRAM/EMPAL. They plan to integrate this land use model with their existing travel demand forecasting systems, in the manner described below.

The fourth set of respondents has developed Or licensed a formal land use model and **integrated** this model into their regional travel demand model in a manner which allows for feedback between transportation and land use over time. This interaction, which most fairly simulates the ways regions actually grow and change over time, has in several cases been applied to analyze the long terms effect of alternative policies (or combinations of policies) designed to reduce regional congestion, improve regional air quality or achieve other important regional policy goals.

Only two regions have implemented techniques for simulating the interactive effects of transportation system performance and household and business locational decisions. Planners in both Seattle and the San Francisco Bay area have developed, tested and are using such systems. Each has limitations, however, which can and should be addressed by modelers in these or other regions. A well developed, fully integrated, state-of-the-art land use/ transportation model does not exist in the United States today.

In fact, while there exists a consensus among academics and theoreticians on the superiority of an interactive approach to land use/transportation modeling,' there are few comparisons of forecasts using an interactive model (in which locational decisions interact with transportation system performance and improvements) and forecasts using a four-step modeling system. There is a dear need for such comparisons as part of any effort to advance the state of transportation planning today.

Specific Forecasting Techniques

The travel demand forecasting techniques used in the major U.S. metropolitan areas are varied and complex. It was not possible to study each in detail to determine its suitability for use in this project. Instead, the study focused on how these models deal with the impacts of land use patterns on transportation forecasts. Other important issues, such as the treatment of non-motorized travel modes (bicycle and walking) and whether the travel speeds and patterns predicted by these techniques are consistent with input speed assumptions, could only be addressed in the more detailed review of Portland's models discussed in the next chapter. It should be noted, however, that few existing travel forecasting systems deal explicitly with non-motorized travel models, and many do not include the kinds of incremental or iterative procedures required to ensure that input travel speed assumptions are consistent with output speed predictions.

In both cases, however, notable exceptions exist. In both the San Francisco Bay Area and in Portland, the travel models are normally iterated using updated travel speed assumptions on each highway facility until the input speeds match those predicted using the final highway volumes. Also, a new travel forecasting system now being developed by the Maryland-National Capital Park Planning Commission includes new methods designed to address both of these issues.

To address the use of land use-related variables in the forecasting systems of the major metropolitan areas, data were gathered from sixteen regional planning agencies. The forecasting systems of all agencies include some form of the relationship of travel as a function of land use. However, the extent of that relationship varies.

Land use, as measured by population, households, and employment totals by zone, is generally incorporated into the first step of the traditional four-step modeling process, trip generation. In most metropolitan areas, the second step, trip distribution, relies on the gravity model, in which no land use variables are inputs. The mode choice model sometimes, but by no means always, includes land use variables. The fourth and final step, trip assignment, does not incorporate such variables. Throughout these four steps, most modeling systems focus exclusively on motorized travel; trips by walkers and bikers are usually not considered.

Sometimes land use variables are further refined, that is, subsets can be distinguished to exhibit a finer level of information. Examples of this further refinement include subdividing population and households by income level, housing type, and/or age of householder. Also, employment can be subdivided, often by industry type. Some forecasting systems also deal with more minor aspects of urban travel demand such as enplanements in airport zones and enrollment levels in school, college, and university zones. The extent of the effect of land use upon transportation, once it has been thus quantified, is usually not investigated further. Little consideration is given to the effects of pedestrian and transit-oriented types of measures upon travel patterns. The typical four-step travel demand models generally are unable to reflect land use variables related to, for example, density/cluster development attributes or accessibility by walking or other nonmotorized means.

Table 4 shows the types and frequency of use of variables as reported by the respondent agencies. Most respondents generally apply the typical approach to travel demand modeling as described above, with and/or variations, such as incorporating an additional land use-related variable at one or another

Table 4. Variables Used Directly in the Modeling Systems of Survey Respondents

Variable Types	Trip Productions	Trip Attractions	Trip Distribution	Mode Choice	Highway Assignment	Transit Assignment	Auto Ownership	Workers per Household	Household Size	Parking Cost
Population	81%	63%	6%	19%	0	0	13%	6%	6%	0
Households	94%	69%	6%	38%	0	0	13%	6%	6%	0
Employment	38%	94%	6%	25%	0	0	67%	0	0	6%
Other Land Use Variables	19%	63%	6%	31%	6%	0	13%	0	0	0
Income	50%	6%	13%	63%	0	0	6%	6%	0	0
Lifecycle Categories	19%	0	0	0	0	0	0	0	0	0
Auto Ownership	50%	0	6%	50%	0	6%	6%	0	0	0
Workers or Labor Force	38%	6%	6%	25%	0	0	6%	0	0	0
Other Demographic Characteristics	44%	44%	6%	25%	0	0	13%	0	0	0
Parking Limitations	6%	0	6%	19%	0	0	6%	0	0	0
Parking Costs	0	0	6%	81%	0	0	6%	0	0	0

point in the four-step process.

Based on the responses received in this survey, certain forecasting systems have characteristics which cause them to stand out. For example, in the system used by the San Francisco Bay Area's Metropolitan Transportation Commission (MTC), there are more and better defined land use variables used in the trip production, trip distribution, and mode choice models. Each of these models includes population, households, and employment variables.

The MTC system merits recognition for its incorporation of variables in its mode choice model. Residential and employment densities, auto ownership, primary vs. secondary wage earners, travel behavior, parking limitations, and parking cost variables are used. The income and worker variables are also present for the home-based work trip purpose. This more comprehensive formulation allows greater policy sensitivity regarding land use-related zonal characteristics than mode choice models from other regions which typically have only three explanatory variables.

The MTC system has created an "interactive" land use/transportation modeling procedure by manually transporting output from its transportation model to its land use model, integrating it as input to a land use forecast for a subsequent time period. By this technique it simulates, at least through a small number of iterations, the interaction effects of congestion on location decisions of households and employers.

In its logit-type trip distribution model MTC includes several land use, worker, parking limitation, and parking cost variables. Other than MTC, all regions except two use the standard gravity model approach Dallas/Fort Worth and Portland. Portland's approach is described below. Dallas/Fort Worth uses an income-stratified gravity model to reflect the fact that attractions and productions with common income categories are likely to generate work trips, while those due to differing income categories will not. MTC's approach, which in effect uses all variables affecting mode choice also in trip distribution, provides a unique level of sensitivity to land use-related variables in its trip distribution models. The variables include income, auto ownership, and the "breadwinner" status of the traveler as significant independent variables.

The Portland region forecasting system also has characteristics of interest for modeling the transportation/land use interaction. This system goes beyond the basic land use data for input into trip productions and attractions, for example, by including life cycle categories and subdividing the employment variable by retail and college types.

For its mode choice models, Portland employs a two-stage approach. The first stage is a choice between motorized vehicular and other modes (e.g., walk and bicycle) and includes land use-related variables such as retail employment within one mile from an attraction, total employment, and retail employment. The second stage determines the motorized vehicular mode shares for each trip purpose. For a more complete forecasting system description, see the following chapter of this volume.

The Maryland-National Capital Park Planning Commission is currently developing a forecasting system with unique features. It includes a number of variables that are pedestrian and transit-sensitive. Examples include the ratio of sidewalk miles to street miles; the percent of jobs and the percent of households within one-half mile of rail stations; and employment density (applied in the mode choice model). It has also developed methods to reflect the effects of higher residential and employment densities on "peak spreading" (the tendency to redistribute peak hour trips to less congested times of day).

The new Maryland forecasting system also incorporates iterative travel forecasting procedures which ensure that the highway travel times predicted for future scenarios are consistent with the times used as inputs to the trip distribution and mode choice models.

The Middlesex-Somerset-Mercer (MSM) Regional Council (located in Princeton, New Jersey) has developed a modeling system worth mentioning because of its method for simulating mode choice without using traditional mode choice models. Instead, vehicular trip reduction factors (TRFS) are applied to vehicular trip rates; vehicles are the only mode with which the forecasting system deals. These TRFs are defined for each transportation policy/land use construct, each of which has been designed to cause trip reduction through carefully selected combinations of the following factors:

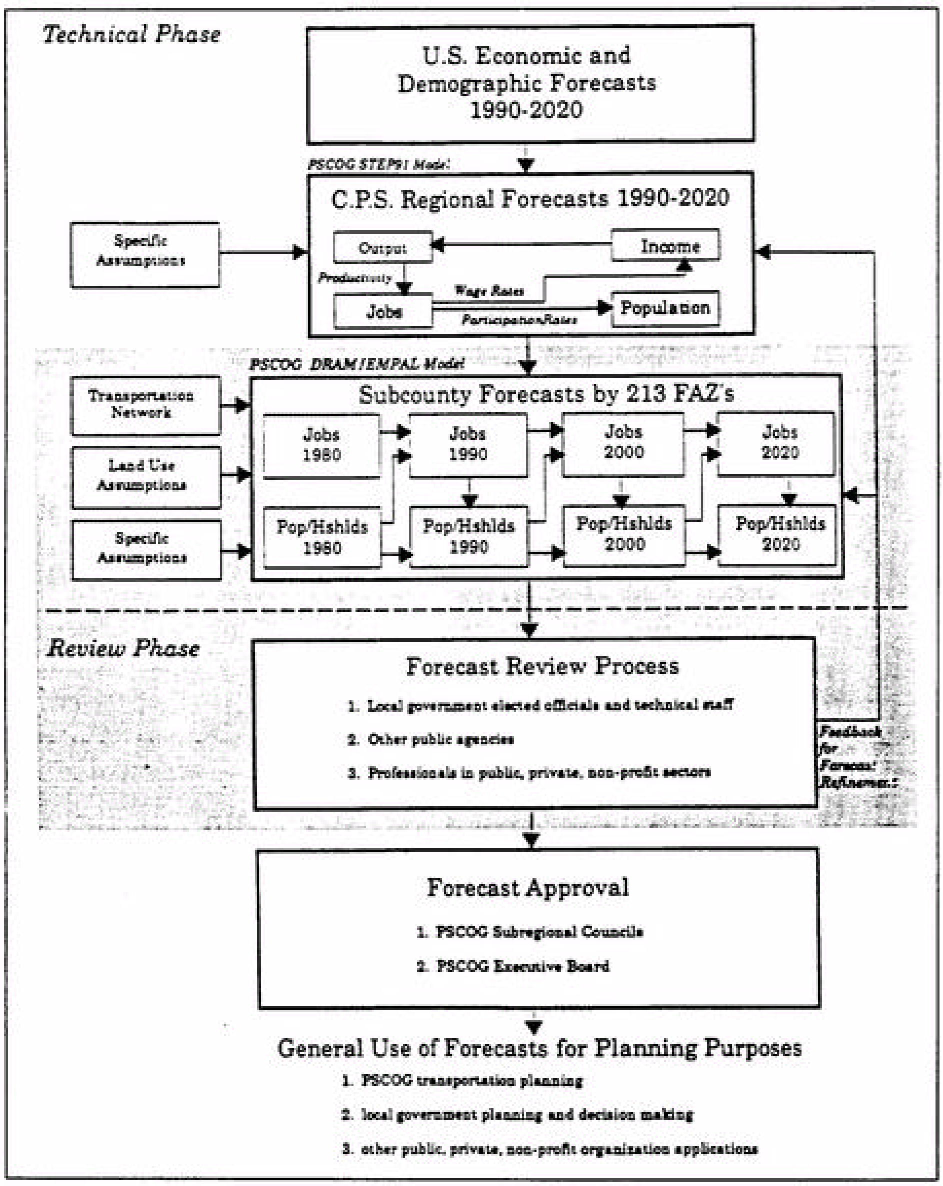
- overall office/retail/housing n-dx,
- jobs/housing ratio,
- total employment,
- design integration,
- proximity to rail transit,
- presence of radial bus service,
- presence of internal bus service,
- constrained parking supply for commercial uses, and
- increased residential density.

These factors are not direct variables in the forecasting system, but they are factors that bring about varying vehicular reductions. TRFs affect the number of trips when applied at the vehicular trip generation stage and are based mainly on recent observations of large-scale suburban activity centers with as many of the factors listed above as possible. The MSM forecasting process thus represents a holistic approach for representing the impacts of land use patterns on vehicular travel.

The Puget Sound Council of Governments is the only U.S. metropolitan area to employ a fully integrated transportation and land use modeling system, making use of DRAM/ EMPAL for land use forecasting. Their innovation is in the routine integration of land use data into their travel demand forecasting procedures.

As shown in Figure 7, the Council's land use forecasting procedure involves the iterative development of population and employment forecasts for each analysis zone at ten-year intervals. (NOTE: The feedback between the transportation model and the land use model is not shown on Figure 7, to facilitate comprehension of the land use forecasting process.) The forecast procedures use travel impedance data generated by the transportation model to allocate employment and households. The final travel demand and land use forecasts are the result of iterative, interactive forecasts for several previous time periods. This approach to forecasting was the basis for comprehensive, long-range regional transportation and land use planning process completed by the Council in 1990.

Figure 7. PSCOG Land Use Modeling Process



Source: Puget Sound Council of Governments

Seattle's forecasting model system, however, contains no formal means of distinguishing the effects of urban design variables (such as pedestrian amenities) or urban form variables (such as density and land use mix) on travel behavior (such as trip generation and mode-split). Furthermore, its travel demand model does not make use of the kinds of enhancements developed and in place in San Francisco, Montgomery County and elsewhere, described above.

The main implication of this survey, in the context of travel demand modeling is that planners improve current practice by incorporating land use variables at stages in the process besides trip generation, as MTC and Portland do in the mode choice step and MTC does in the trip distribution step. Secondly, they can include variables that are particularly pedestrian- and transit-sensitive as in the Maryland-

National Capital Park/Planning Commission's forecasting system. Thirdly, planners can refine land use data by disaggregating employment by industry type.

Changes of this nature keep the four-step process basically intact, however. To simulate the interactive nature of transportation and land use in a single forecasting system, planners need to adopt new model structures, such as those that fully integrate land use and transportation forecasting procedures.

Public Policy Applications

A set of public policy issues nearly as numerous as the number of jurisdictions themselves is impelling planners and decision makers to improve their land use/transportation modeling techniques. Interviewees identified nearly a dozen distinctive issues on the minds of voters and elected officials

Table 5. Policy Issues Requiring Enhanced Transportation/Land Use Modeling

• Congestion Management	• Commuter Rail Construction/ Extensions
• Long-Range Transportation Improvements	• Airport Siting and Expansion
• Air Quality Management	• Housing Location and Price
• Downtown Revitalization	• Private Financing of Transportation Improvements
• Urban and Regional Form	• Locating Future Public Facilities
• Transit Construction/Extensions	

whose resolution will be aided by better models and planning practice. (See Table 5.)

Congestion itself is at the forefront of these concerns. Across the United States urban and suburban congestion has reached high levels, with further congestion clearly on the horizon. From coast to coast, respondents indicated that congestion was a pressing regional policy issue.

The routine preparation and updating of regional transportation plans is leading a number of jurisdictions to review the way they use land use data. In some cases these plans are mandated by state law (Los Angeles, San Francisco, Portland) in others they are the routine updates required by good planning practice (Boston, Dallas, Kansas City). In all cases, planners acknowledge that the time has come to improve the quality of land use data.

Concerns over air quality are concentrated in the West. Los Angeles, Orange County, Phoenix, and San Diego all are being driven to review their land use modeling procedures and their land use policies and plans to reach compliance with regional and federal air quality standards.

A widespread concern for urban form is clearly leading many jurisdictions to consider better modeling procedures. Respondents across the country share a concern for the effects decentralization and suburbanization are having on travel demand patterns. The relationships between density, niix, and intensity of land uses and travel behavior are on the minds of all respondents.

Specific plans for construction or expansion of light or heavy rail systems are pushing planners in at least seven jurisdictions (Kansas City, Miami, Dallas, St. Louis, Minneapolis, Orange County and Portland) to review the relationships between transportation investment and land use. In addition, commuter rail planners in other jurisdictions (such as Boston) are raising the same questions.

New highway construction planned for the Phoenix and Washington D.C. regions has led planners in those jurisdictions to rethink the land use/transportation link. Plans for a third major airport in Chicago are raising similar concerns there. More generally, concerns over the need for additional public facilities including schools, sewer, and water have led planners to rethink the role of integrated transportation and land use planning in San Diego.

The localized effects of transportation investments on development in several jurisdictions (suburban New Jersey, Minneapolis-St. Paul and Chicago) have led planners to a more rigorous examination of ways to allocate the costs for transportation investments between the public and private sectors. In Kansas City a recent, strong interest in the role of the downtown in overall regional growth has lead to a fresh examination of transportation's contribution to urban form.

In Los Angeles and elsewhere, a concern over housing affordability and its link to urban sprawl is behind many of the questions being asked about the ways in which transportation affects locational decisions.

This nexus of issues, while diverse, indicates clearly that the relationships between transportation and land use are beginning to be better understood. As broad knowledge of the interactive effects of each on the other becomes established in the public's mind, planners are being pressed for ways in which they can forecast more precisely. These issues clearly are not transitory. The number of communities focusing on these concerns is still growing, as is the intensity of their interest.

Relationships to Air Quality Planning

As cited earlier, the survey disclosed only a small number of regions (all in California) which are actively examining the role which land use can play in improving air quality. These regions are under substantial pressure to comply more fully and more quickly with national air quality standards.

In other states, the researchers found that land use planning as a policy tool to improve air quality is not ranked highly on the fist of policies currently under examination.

Modeler's Needs

When asked to identify the major gaps in current modeling practice, interviewees described a set of concerns which can be grouped into three broad topics.

First, most of the interviewees cited a lack of adequate data as a major impediment to the improvement of modeling practice today. Planners in Los Angeles, Boston, New York, Dallas and Houston all indicated concern over the quality of both current and historic land use data available for modeling purposes. An equal number of respondents cited the quality and quantity of data on travel behavior as an obstacle. Planners from Kansas City, Detroit, New York and Minneapolis, among others, noted that the origin/destination data on which they based their models is far out of date, and inadequate to reflect the growth and change which has occurred in their regions. All respondents underscored the critical importance of funding new data collection in this area.

Along similar lines, planners in New Jersey, Texas and Massachusetts cited an insufficient understanding of the effects of different land uses on trip generation rates. They and others are seeking a much better overview of the ways in which alternative land use patterns and transportation systems affect both the numbers of trips and the means by which they are taken.

Secondly, respondents expressed concern over the options available for implementing long range transportation and land use plans. Planners in Kansas City, the New York region, and Houston expressed concern over the inability of decision makers to reach consensus on local and regional land use policies. In addition, they voiced concerns over the inadequacy of current tools (policies) to affect regional land use. They and others (in Chicago, Orange County, and elsewhere) expressed disappointment with the process of obtaining interagency coordination. These concerns included the inability of land use and transportation agencies to coordinate their respective plans, as well as the inability of transportation planners at different levels of government to cooperate adequately.

Thirdly, respondents identified concerns related to modeling practice itself. In some cases (such as Miami) these concerns focused on the need for enhancements to existing travel demand forecasting models to reflect better the effects of various public policies (such as the array demand management techniques). A broader concern, however, related to the absence of models which explicitly integrate transportation and land use forecasting into a single package. While a few regions (San Francisco and Seattle) have achieved success in this area, the vast majority of regional respondents still view this as a goal. In most cases it is, indeed, a distant goal, one to which they aspire but about which they have little knowledge and no tools.

Summary Assessment

This survey of transportation modeling practice in principal metropolitan areas in the United States has confirmed the predominance of the traditional, four-step transportation planning process, in which land use data serve as an input to the first step of the process and play no other role in affecting forecasts of travel demand. Of the nearly two dozen metropolitan area organizations surveyed, most use the four-step planning process today, though several are making a transition to integrated modeling techniques. Household and employment estimates are allocated to analysis zones by a process of consensus, rather than by the use of any more rigorous, quantitative methods.

A small subset of these agencies have innovated by introducing land use forecasting models into their transportation planning process. However, only two agencies were identified which have developed techniques for interactive transportation-land use modeling - the Metropolitan Transportation Commission in the San Francisco Bay Area and the Puget Sound (Seattle) Council of Governments.

However, discussions with transportation planners in Boston, Los Angeles and Orange County, among others, yielded information on the ways in which agencies in these areas plan to introduce more rigorous land use forecasting and/or interactive transportation/land use forecasting procedures. Clearly, additional agencies will be doing similar work in the future.

A Aide variety of policy issues and problems is impelling planners and public officials to identify better tools to forecast travel demand. Nearly a dozen issues ranging from broad concerns with traffic congestion and regional land use and urban form to very specific concerns over downtown revitalization, airport expansion or facility financing are leading staff and officials across the country to rethink their modeling procedures.

In addition to acquiring better and more up-to-date information on travel behavior and developing better means to implement their plans, respondents to the survey identified the lack of adequate modeling tools as one of their three principal needs today. Clearly, many of these practitioners have not evaluated, and may not even know of, the options available for enhancing their land use/ transportation modeling capability. Information on models available today, assembled in the first chapter of this volume, should serve to close this knowledge gap in the future.

In conclusion, there is a clear trend in the state-of-the-art in modeling today toward the integration of land use and transportation models, in response to two needs. First, policymakers need to understand the transportation consequences of alternative land use plans for neighborhoods, communities and regions. Secondly, they need to understand the ways in which traffic congestion and new transportation investments affect land development patterns. In both these cases, they need to foresee the ways in which the complex forces shaping metropolitan areas produce results both intended and unintended, affecting the quality of life of their constituents.

The trend toward integrated models is clear, but not complete. Additional work developing, validating and using these models for decision-making must occur for the process to retain its momentum and reach an outcome satisfying to planners, policy-makers and citizens alike.

CHAPTER 3: THE PORTLAND FORECASTING SYSTEM

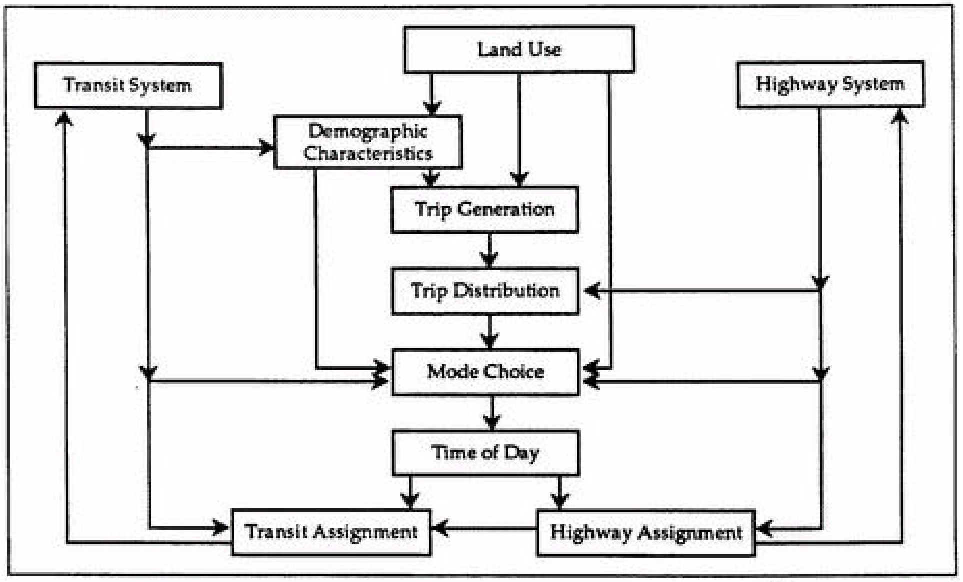
Introduction

This chapter describes the characteristics of the travel demand modeling system used in the Portland, Oregon metropolitan area and evaluates its limitations in light of best practice methods, available model system enhancements, and state-of-the-art knowledge.

The chapter focuses on the linkages between the system's land use and transportation models and on the land use variables used in the transportation model itself. It describes the major dimensions of the modeling system in detail. The limitations of the model system and its characteristics are identified in the Summary Assessment.

The major elements of the Portland land use and transportation forecasting system, and their relationships, are shown in Figure 8. Each box in the flow diagram represents several submodels which, taken together, provide forecasts of a particular set of variables related to transportation in the Portland metropolitan area. The arrows between boxes represent data flows: outputs of preceding models which are used as inputs to succeeding models. A detailed description of the submodels included in the Portland forecasting system is provided in the Metropolitan Service District report Travel Forecasting Methodology Report: Westside Light Rafl Prood (September 1989).

Figure 8. General Structure of the Portland Land Use and Transportation Forecasting System



Model Dimensions and Subdivisions

Before describing the purpose and nature of each set of submodels, it is useful to outline the significant dimensions or subdivisions which affect both model complexity and level of detail of the resulting forecasts.

Geographical Areas. At the finest level, the Portland area is subdivided into over 1800 separate geographical units. For typical travel forecasts, these are aggregated into 300-400 traffic analysis zones. For land use forecasting, total development is initially estimated for 20 districts, followed by allocations to all 1,800 units within these districts.

Land Use and Demographic Variables. The basic variables provided by Portland's land use forecasting system are population; households by four categories of age of the head of household; housing units; average household income; total, retail and college employment; and college students. As demographic characteristics are further detailed, distributions of households by various combinations of the following six variables are developed:

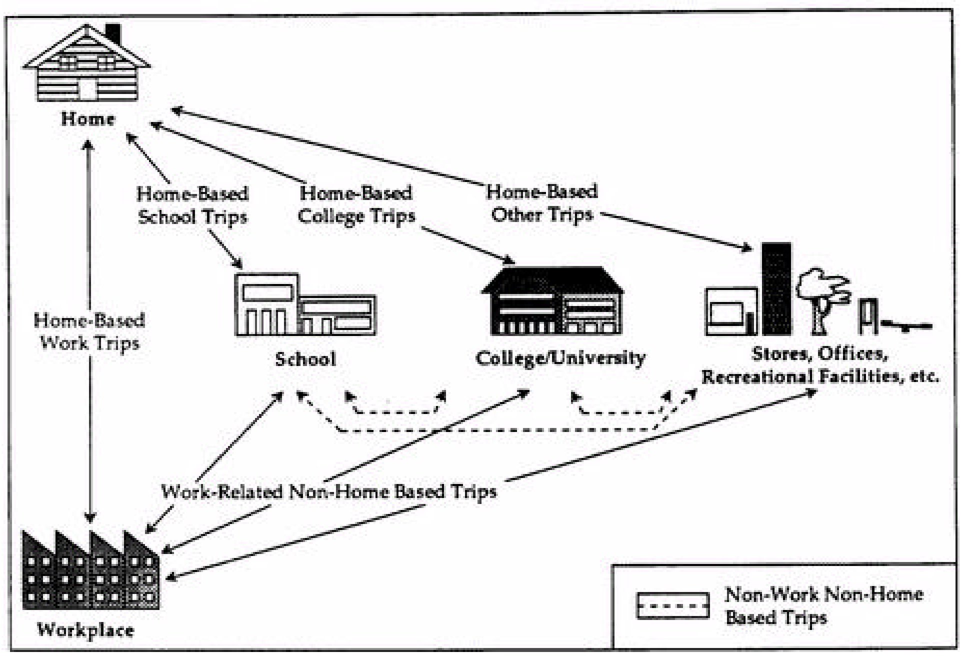
- household size - 4 categories;
- household income - 4 categories;
- age of the head of household - 4 categories;
- workers per household - 4 categories;
- autos per household - 4 categories; and
- children per household - 4 categories.

Trip Purposes. Six trip purposes, illustrated in Figure 9, are each predicted by separate trip generation, trip distribution, and mode choice submodels:

- home-based work: trips between home and workplaces;

- home-based school trips;
- home-based college trips;
- home-based other: all other trips starting or ending at home;
- work-related non-home based: all trips starting or ending at work and not starting
- or ending at home; and

Figure 9. Trip Purpose Used in the Portland Travel Model System



- non-work/non-home based: all other trips not starting or ending at home.

Modes of Travel. For each trip purpose, pedestrian or bicycle trips and vehicular trips are predicted. Vehicular trips are then further subdivided by specific modes which depend on trip purpose. Home-work trips are subdivided into five modes:

- drive alone;
- shared ride driver;
- shared ride passenger;
- transit with walk access; and
- transit with auto access.

Vehicular home-school trips are predicted for four somewhat different modes:

- auto driver;
- auto passenger;
- public transit; and
- school bus.

All other vehicular trips are subdivided into three modes: auto driver, auto passenger, and transit.

Times of Day. With the exception of the time of day models, au transportation forecasting deals with total trips on an average weekday. Time of day factors are then applied to provide trips during AM and PM peak hours and peak 2-hour periods, and during all off-peak hours.

Network Facilities. The highway and transit assignment procedures predict travel volumes on computer-coded networks consisting of 10,000 one-way highway links, many of which also serve transit routes for which transit volumes are forecast.

Major Model Element Descriptions

The following subsections discuss each model shown in Figure 8 in turn. In each case, the model's purpose and its general forecasting strategy is described and its input and output variables are identified. The linkages between land use and transportation models are identified, as well as the cases where these linkages are desirable but missing.

Land Use Forecasting

The Portland forecasting system begins with a land use forecasting model which provides projections of future population, households, and employment by analysis zone. This model is made up of several submodels, some formalized as computerized procedures and others consisting of person-to-person discussions, negotiations, and agreements. These submodels, as used to develop Portland's most recent land use forecasts for 1995 and 2010, include:

Econometric forecasts of total employment for the entire metropolitan area, obtained from a model developed by Wharton Econometric Forecasting Associates.

Trends/projections of Portland's shares of statewide employment by category.

The Regional Growth Forum, made up of representatives of business, government and academia in the region, which served as an “expert panel” to select a final set of growth rates for major employment categories.

A regional population forecast obtained from a model at the Portland State Center for Population Research and Census, which considers the employment forecast developed by the Regional Growth Forum, projected labor force participation and unemployment rates, and the aging of the present population.

Future population and employment growth totals were allocated to 20 districts within the metropolitan area and to political jurisdictions within these districts. This process occurred in growth allocation workshops in which planners for local jurisdictions negotiated their respective shares of the regional totals based on their state-approved Comprehensive Plans and on the current plans of local developers to the extent that these were known. The Comprehensive Plans include expected “build out” levels of development, while the plans of local developers deal mainly with the next 5 to 1 0-year period.

Within each political jurisdiction, the final allocations to small areas (ultimately 1,800 underlying zones) were performed either by local planners or by Metro, based on available land and development trends within political jurisdictions.

In summary, Metro's land use forecasts are based on a consensus process rather than on the results of formalized forecasting models. Furthermore, future transportation systems, projected travel patterns, and projected transportation levels of service are not considered explicitly in developing these forecasts. Of course, the forecasts do depend on implicit assumptions about future levels of public investment in several facilities and services including education, water supply, sewer systems, and transportation - which will be needed to support the forecasted levels of growth.

Highway and Transit Systems

The specification of present and future highway and transit systems is a crucial step in the Portland forecasting system. Detailed computerized descriptions of these facilities are needed to provide measures of transportation levels of service, such as travel times and costs for input to many of the models included in the system. Initially, these measures must be estimated based on current traffic count and transit patronage levels, but as future usage levels are predicted in subsequent models, these initial estimates are refined, if necessary, to reflect the predicted traffic and patronage levels. Following these refinements, the trip distribution, mode choice, and highway assignment models are rerun to ensure that consistent travel times are used throughout the travel forecasting process.

Both existing and proposed future highway facilities are described by specifying the following characteristics for each one-way link:

- Distance;
- Free-flow (no traffic) speed;
- Number of lanes;
- Capacity per lane;
- Coordinates of the starting and ending intersections (nodes);
- Codes to indicate link delay characteristics, jurisdiction, and link type (freeway, arterial, collector, etc.); and
- Existing volume levels.

Existing and proposed future transit routes are described by specifying the sequence of highway or transit-only links which they traverse, as well as the following route characteristics:

- Route name;
- Route mode (bus or light rail);
- Transit vehicle type;
- Headway or interarrival time;
- Default speed on transit-only links; and
- Codes to indicate layover times and, for each link on the route, transit delay characteristics and stop times.

After highway and transit networks are specified using these variables, minimum path programs are used to determine corresponding levels of service between all zone pairs in the study area. For highway networks, these levels of service consist of:

- Peak and off-peak travel times;
- Travel distance; and

- Travel cost.

For transit networks, the following level of service measures are determined between all zone pairs for both peak and off-peak conditions:

- In-vehicle travel times;
- Out-of-vehicle travel times (walk, wait, transfer); and
- Transit fares.

In addition, the transit network is used to determine the number of employment opportunities within 30 minutes of total travel time by transit from each zone.

Demographic Characteristics

The next major submodel provides detailed forecasts of demographic characteristics for each analysis zone. The total employment provided by the land use forecast is subdivided into retail and other categories. Population and household forecasts by zone are subdivided into many categories based on household size, age of household head, income level, number of workers, number of autos, and number of children.

Subdivisions of households by size, income, and age of household head are obtained using demographic techniques such as a cohort survival model, to provide individual or marginal distributions of households by each of these three variables in each zone. Then, a three-dimensional matrix adjustment process is used to revise a base-year household matrix to match the new marginal distributions. Models based on travel survey data are then used to further subdivide the households by number of workers, autos and children per household. The variables included in these models are:

- Household size;
- Income class;
- Age of household head;
- Workers per household (after this variable is estimated using the worker model); and
- Number of employment opportunities within thirty minutes of the zone by transit.

This set of models for predicting demographic characteristics by zone provides much more detail on the households in each zone than does the typical metropolitan area's travel forecasting system, but it includes only a single variable which reflects the transportation system. This variable is the number of employment opportunities within thirty minutes by transit, which affects auto ownership levels. Furthermore, this variable is the only transportation variable which explicitly affects any aspect of Portland's land use and demographic forecasts.

Trip Generation

Portland's trip generation models predict trip origins and destinations by each of the six trip purposes identified above. In general, two models exist for each trip purpose, one to estimate trip ends at home (for home-based trips) or at work (for non-home based work-related trips) and one to estimate the other ends of these trips. These models depend on the demographic characteristics of households predicted in the previous set of models, and on the following characteristics which attract trips to non-home locations:

- Total employment;
- Retail employment;
- Total households; and
- Students and employees at colleges.

Portland's trip generation procedures make extensive use of a number of household characteristics, but do not reflect types of neighborhoods, such as single family versus multiple family housing or as measured by housing density levels. Also not considered are large multi-use developments providing housing, commercial, and employment opportunities in close proximity to each other. Finally, measures of the concentration of trip attractions, such as employment density, are not considered. Empirical evidence is available nationally which suggests that these urban design factors tend to result in trip rate reductions. (2)

Portland's trip generation Procedures also fail to include considerations of how easy it is to travel to various destinations from each zone considered as a trip generator. Thus, the quality of the transportation system serving a zone both highway and transit facilities can be expected to affect the total number of trips made to and from the zone. A high level of transit service, for example, is likely to result in more trips made from zones with many transit-dependent residents. Portland's failure to include variables measuring urban design and transportation system characteristics in its trip generation models is consistent with the practices in all but a few U.S. metropolitan areas, but represents a major shortcoming of its models for use in this project.

Trip Distribution

Portland's trip distribution models predict the linkages between the trip origins and destinations provided by its trip generation models. Separate trip distribution models exist for each of the six trip purposes. In each, travel times - peak times for work trips and off-peak times for all other trips - provide a measure of the separation or travel impedance between origin and destination zones. The time used for each zone pair is either the highway time or the transit time, whichever is shortest. (Usually the highway time is shortest.) Trips are more likely to exist between zones which are close to each other, but the model reflects the average trip lengths which actually occur as travelers choose to make a wide range of trip lengths, ranging from very short intrazonal trips to very long trips.

Portland's use of a single variable in its trip distribution models (beyond the trip origins and destinations provided by the trip generation models) is also typical of standard U.S. practice. However, this practice is significantly deficient because it fails to consider the impacts of transit systems and levels of service, urban design characteristics, and demographic characteristics on trip linkages. Thus, the Portland trip distribution models are not sensitive to variations such as the following:

The tendency of white-collar workers to work in the Portland CBD, and of blue-collar workers to work in the region's industrial areas.

The tendency of transit-dependent households to live and work in areas well served by transit and to live within walking distances of commercial areas providing essential goods.

The tendency for higher income households to live farther from work and to make longer non-work trips than low income households.

Mode Choice

Portland has developed a set of mode choice models which consider many factors affecting travelers' choice of travel mode for the trips predicted by the trip distribution models. These models, specific to trip purpose, include land use, demographic, highway system and transit system variables. Unlike most U.S. areas, the models consider walking and bicycles as potential travel modes for trips shorter than observed maximum distances for these “non-vehicular” modes.

The land use and demographic variables which are considered in the mode choice models are the following:

- Autos per worker;
- Autos per household;
- Trip end area types: (CBD, City of Portland, eastern suburbs, western suburbs, or Clark County);
- Retail employment in production zone and within one mile of attraction zone;
- Age of household head;
- Total employment in production zone, within one mile of production zone, and within one mile of attraction zone; and
- Other employment in production zone.

The Portland mode choice models are deficient because they lack variables related to detailed aspects of urban design which affect transit and pedestrian friendliness. Measures of the proportion of trip lengths for which sidewalks or bikeways exist, the distances of buildings from public streets, and the availability of bus stop shelters are not included in the models, but these factors can be important in attracting residents to walk, bike, and transit modes.

Portland's mode choice models for all purposes except home-based work also fail to consider transportation system variables related to high-occupancy vehicle (HOV) lanes or other HOV priority treatments. Because HOV priority treatments tend to be oriented to peak period work travel, this is not a major deficiency. In addition, the present mode choice models do not consider employer-based car-pooling and van-pooling incentives, such as parking preferences and ride-share matching. Thus, while Portland's mode choice models have several features placing them at the cutting edge of the current state of the practice in the U.S., they nevertheless retain deficiencies which limit their usefulness. In addition, the models may be able to be enhanced by allowing for better differentiation between the attractiveness of various transit modes.

Time of Day

The Portland model system includes purpose-specific time of day factors which are applied to daily trips to obtain trips by AM and PM peak hours or peak two-hour periods. These factors are not related to land use characteristics, such as density levels, employment types, and the mix of commercial activities in a zone; or to demographic characteristics such as occupation type. These relationships would be useful in evaluating detailed urban design options for selected development areas.

Highway Assignment

Portland's highway assignment process represents the best of the current state of the practice. Vehicle trips per hour are assigned to multiple paths between origins and destinations in an iterative process, termed “network equilibrium,” which results in the use of a number of paths having approximately equal travel times. As the procedure's iterations are carried out, additional paths are added, and facility volumes and times are adjusted toward an equilibrium state. Land use and demographic variables are not included in this process, but no significant relationships have been found linking these variables with driver's choices of urban highway routes. Thus, the only deficiency of Portland's highway assignment procedure is its lack of explicit consideration of HOVs and highway facilities reserved for their use.

After the highway assignment process has been completed, the resulting auto volumes and travel times by facility are used to update the highway system. The updated highway system is then used, when necessary, to re-estimate system zone-to-zone travel times for use in a new iteration of the trip distribution and mode choice models. Ideally, this information, plus transit levels of service, would also provide inputs to the forecasts of land use for future years and current-year trip generation.

Transit Assignment

Portland's transit assignment process also represents the best of the current state of the practice. Transit trips are allocated to paths based on weighted path travel times. In-vehicle travel times on highway links are determined by adjusting the final auto times to reflect typical differences between bus and auto speeds due to bus stops and differences in acceleration rates.

Summary Assessment

The Portland land use/transportation models are both complex and detailed. In total, they represent one of the most advanced travel forecasting systems available in the United States. In addition, they have been estimated using advanced statistical procedures which ensure that they accurately reflect the behavior of travelers in the Portland area.

In spite of all the laudable features, however, the Portland models have two major deficiencies which limit their usefulness, not only for this project, but also for the full consideration of many alternative land use/urban design/transportation strategies which Portland should be evaluating as it decides how the Portland area will change and develop in the future. These two deficiencies are:

- The lack of a formal feedback mechanism from the transportation system to the land use forecasting process; and
- An inadequate consideration of many variables representing detailed urban design options which can slow future vehicular travel growth in Portland.

Regarding the first problem, Portland's approach makes it very difficult to anticipate the system responses to a particular policy. In its traditional analysis, a series of exogenously produced estimates of trip demands, in the form of origin/destination trip matrices, is calculated. The employment locations and household locations, spatially distributed through a large region, are prepared first. Estimates are made of numbers of trips originating from each zone and terminating in each zone. Then, distribution procedures are evoked. These trips are assigned to the links of the highway network. Then, based on the number of trips using each link, an estimate is made of the congestion.

Once congestion levels have been calculated, it is possible to trace through the network the minimum cost paths from each zone to each other zone. The conventional analysis procedure then identifies links which should have capacity increases.

The difficulty with this procedure is that the congestion resulting from the initial estimates of trip makers, and thereby from the initial estimates of the locations of employment and households, would result, over a long-term span of years, in a re-arrangement of the locations of employment and households. To properly estimate the congestion, it is necessary to know the congestion; and to properly know the congestion, it is necessary to know the location of employment and population and the resulting demand for trip flow on ' the network. This is a classical example of a system which can only be properly analyzed by use of some form of interactive technique which includes both the feed-forward and the feed-back connections among the elements of the system.

Regarding the second problem, it is now well known that urban design and development patterns do matter when individual travel choices are being made. Studies of the conditions under which transit works, and other commute alternatives can prosper, have identified four key interrelated dimensions - density, development size, land use mix, and design features (scale, coverage, etc.) (3,4)

Of particular importance is the size of the downtown or other compact center. Focusing retail and office uses in a few large centers results in higher transit use and ridesharing than if these activities are located in several smaller centers. Mixing and clustering land uses can add greatly to the convenience and attractiveness of commute alternatives, making it possible for the employee to run errands or go out to lunch without a car. Reductions of parking availability and increased parking charges are also critical factors in mode choice.

Land uses and densities also matter at the residential end of the trip. For example, where residential density is not only low but development is scattered over the landscape, and employment and retail centers also are dispersed, transit service is unlikely to attract enough riders to justify its presence. Walking and biking trips also tend to be impractical in these areas.

Recent urban design projects have attempted to moderate travel demand and influence mode choice through a conscious design process. (5) Designs provide for shopping and services near transit station entrances and exits; apartments within easy access to department stores and work places; places to meet friends or engage in recreation after work; convenience goods shopping near single family residences; convenient places to wait for the bus or carpool; direct bike routes and pedestrian ways linking housing to commercial centers and schools.

One of the significant challenges of “Making the Land Use/Transportation/Air Quality Connection” is to develop and apply enhanced models for Portland which take these findings and factors into account. These enhanced models will overcome many of the limitations discussed above and thus provide a useful tool for exploring urban design options designed to reduce vehicular travel, and for demonstrating the impacts of transportation improvement decisions on land use growth patterns.

Appendix A: Regional Summaries

A summary of the most relevant findings and facts from each of the metropolitan areas participating in the survey described in Chapter 2 follows.

New York/New Jersey/Connecticut

In the metropolitan New York region, consisting of parts of three states, no single set of land use forecasts exists. Each state and many substate agencies prepare their own travel demand forecasts and land use inputs as required. Among the major organizations involved in forecasting are the New York Metropolitan Transportation Council, the Port Authority of New York and New Jersey, the Regional Plan Association, three state departments of transportation (DOTs), and individual counties in the states of New York, New Jersey and Connecticut.

Land use inputs to the transportation demand modeling process are adapted from state and regional demographic and economic forecasts. The New Jersey and Connecticut DOTs have their own travel demand models. The Metropolitan Transit Authority has a journey to work model for the tri-state area. The Port Authority prepares population and employment forecasts.

Under an Urban Mass Transportation Administration (UMTA) grant, work has begun on a model relating transit accessibility to land price and demand for the Regional Plan Association. In addition, the Association is undertaking work on its third Regional Plan which involves a transportation element.

Los Angeles

Los Angeles, through its Southern California Association of Governments (SCAG), is in the process of calibrating a land use model (DRAM/EMPAL) as part of a new regional mobility plan. The plan focuses on the relationship between urban and regional form, transportation and air quality. The land use forecasting model has not yet been fully calibrated and no integration with travel demand forecasting has been undertaken as yet.

Locally developed economic and demographic forecasts are used as the basis for the allocation of population, households and employment by analysis zone. A combination of technical analyses and discussions are the basis for this allocation. While the Association of Governments has found this process to be inadequate, the technical difficulties of calibrating a land use model for so large a region have caused delays in the introduction of a formal regional land use model.

SCAG is focusing on the effects of alternative regional development patterns as a Policy to bring about compliance with regional air quality standards; however, it has not achieved consensus on an appropriate land use policy. Discussion has evolved from a focus on jobs-housing balance to a focus on how various urban forms affect travel demand.

Chicago

In the Chicago region, the Chicago Area Transportation Study (CATS) staff offer a regional travel demand forecast. Locally developed economic and demographic forecasts for the region are prepared by the Northeastern Illinois Planning Commission (NEPC) and used by the CATS staff. The Commission allocates growth to one-half mile square units in Illinois through a combination of technical analyses and interagency review. The allocation of land uses and economic activity for the Indiana portion of the region are done in a less quantitative fashion.

During the 1970's, a land use allocation model was employed by NIPC, but the model is no longer frequently used for regional land use forecasting purposes. NIPC has initiated a multi-year process which is expected to result in the use of a more structured model at some future date.

San Francisco

The San Francisco Bay Area employs perhaps the most sophisticated combination of modeling techniques of any major region in the United States. It has developed its own land use forecasting model (POLIS) which is capable of providing substantial sensitivity to the relationship between transportation and land use. Output from this regional land use model is carefully integrated into regional and travel demand forecasting. In addition, substantial local review of the regional forecast is also employed.

The Projective Optimization Land Use Information System (POLIS) allocates households and jobs to 114 Bay Area analysis zones. Subregional area models take POLIS zones and allocate households and employment to census tracts based on many variables.

Clearly the Bay Area is an innovator in the application of transportation/land use modeling techniques. Several public policy issues oblige the Association of Bay Area Governments and the Metropolitan Transportation Commission to keep themselves at the leading edge of practice in this area. These issues include long-range transportation plans, short-range congestion management programs, regional air quality concerns and ongoing litigation concerning the land use effects of proposed transportation investments.

The POLIS model has been used for a variety of land use policy simulations. Results of relevant simulations are available from the Association of Bay Area Governments.

Detroit

The Southeastern Michigan Council of Governments (SEMCOG) employs a traditional four step transportation demand modeling process, in which locally developed demographic and economic forecasts are allocated by consensus to its various analysis zones. The region experimented in the mid 1970's with a land use scenario approach to travel demand forecasting but later abandoned it.

Boston

The Central Transportation Planning Staff (CTPS) works with the Metropolitan Area Planning Commission (MAPC) on transportation and land use issues. To date their use of land use data can be categorized as traditional. However CTPS has recently begun the process of installing and calibrating DRAM/EMPAL for eventual integration into its region wide travel demand forecasting.

Separate land use forecasts have been prepared for Boston's Central Business District, as input to network models for the Central Artery/Third Harbor tunnel project. These models also use the four-step process.

CTPS is in the process of enhancing its air quality modeling capabilities as well as its travel demand forecasting procedures.

Dallas

The North Central Texas Council of Governments has for sometime employed DRAM/ EMPAL to prepare regional land use forecasts. The most recent forecast was completed in 1986. The results of this formal model are used as an input to the traditional four step travel demand forecasting process; the Council has not developed an interactive land use/ transportation modeling capacity.

In a federally funded project focusing on suburban mobility, the Council discussed the role which land use can play in affecting overall travel demand. The Council is overseeing the implementation of recommendations resulting from this project.

Plans are underway to enhance regional mobility, both through the expansion of the region's highway system and the introduction of HOV service, light rail and commuter rail. While all these projects are still in the planning stages, land use issues are being examined.

Washington, D.C.

The Washington metropolitan area Council of Governments (WASHCOG) uses a locally developed economic and demographic forecast and allocates land uses to zones through a “give and take process to reach consensus”. This cooperative forecasting process is updated every three to four years, using several land use scenarios.

The agency's travel demand modeling capabilities are, however, quite sophisticated. They have made use of innovations regarding mode split and other variables, as developed by local transportation modelers. (See discussion on Montgomery County, in Chapter 2, above.)

In addition WASHCOG has undertaken a special study, recently completed, in which the travel demand consequences of alternative regional land use plans have been simulated. Study results will be available soon from the Council.

Houston

The Houston-Galveston Area Council (HGAC) has had several experiences with land use modeling during the 1980's. It used a growth allocation model developed by the Rice Center during the early 1980's and briefly in 1986, but not since. Currently the Council is calibrating the DRAM/EMPAL model. Eventually the Council hopes to integrate its transportation and land use modeling capabilities. The Council currently is relying on 1982 land use data.

Miami

Transportation and land use planning in Miami is governed by Florida's statewide growth management planning law, which emphasizes concurrent provision of adequate infrastructure as a condition for development approvals. The Metropolitan Planning Organization analyzes proposed land use amendments to local general plans, while the County Planning Department allocates forecasts of households and employment, updated at five year intervals. Use of land use data in travel demand forecasting is traditional.

St. Louis

The East-West Gateway Council of Governments oversees transportation planning for the eight county, bi-state St. Louis metropolitan area. Use of land use data in the forecasting process is traditional. Growth is allocated through an “intuitive approach” involving an examination of available land areas, recent land absorption and current zoning policy.

Seattle

In the four county Seattle region, the Puget Sound Council of Governments has recently completed a multi-year process of preparing a long-range regional transportation and land use plan. The plan uses an integrated transportation and land use model, with DRAM/EMPAL. The Council used the integrated modeling system to develop at least four alternative long-range regional transportation and land use plans and to model the consequences of their implementation. It conducted extensive technical studies using the modeling system. An extensive program of public education and discussion resulted in the selection of one of the long-range land use/transportation alternatives as the preferred vision for regional growth through the year 2020. Copies of relevant technical studies can be obtained from the Council.

San Diego

The San Diego Association of Governments (SANDAG) has been using formal land use models for many years. They are currently replacing their reliance on the PLUM land use modeling system with the DRAM/EMPAL system.

The Association's land use forecasting process begins with a set of generalized current uses developed from aerial photos. After introducing development constraint data and general plan data, the PLUM model allocates activity by zones. It allocated residences based on journey to work characteristics, zonal attractiveness and development capacity. SANDAG's land use modeling has not resulted in the integration of land use and transportation models yet.

Phoenix

The Maricopa Association of Governments, in cooperation with the state's Department of Transportation, prepares travel demand forecasts using the traditional four step approach. They allocate state-wide employment and demographic forecasts to zones by a methodology which staff acknowledged to be simplistic.

During the 1970's the Association used the EMPIRIC modeling system, a land use forecasting model popular at that time, but it has shifted away from it. The results of recent attempts to allocate growth by other means have proved disappointing, and the Association will be investigating the introduction of new models or procedures.

Orange County

Orange County prepares its own population, housing and employment projections for the County and its 69 planning areas. The projections are adopted by the County's Board of Supervisors, then disaggregated by traditional means and used in the four step planning process. The County is installing and calibrating the DRAM/EMPAL land use model for use in future forecasts and simulations.

Concerns about regional air quality, public transportation feasibility and growth management are leading the County to become innovative in the application of integrated modeling techniques.

Minneapolis-St. Paul

While the Twin Cities region has a well earned reputation for innovative solutions to regional problems, the Metropolitan Council employs the traditional four step transportation forecasting process. It prepares population, household and employment forecasts and assigns them by consensus to analysis zones.

An extensive, recently completed travel behavior survey will lead to the introduction to updated data for modeling within a few years. To date, innovations in managing regional travel demands have focused on local ordinances rather than regional policy studies.

Kansas City

The Mid-America Regional Council of Governments was an early user of formal land use models. It still uses a modified version of the DRAM/EMPAL forecasting package to allocate regional growth. The Council continues to use the traditional four step planning process in its demand modeling work.

Princeton, NJ

Midway between the Philadelphia and New York regions, the Middlesex-Somerset-Mercer Regional Council, a small non-profit organization, has undertaken a multi-year planning process in cooperation with the region's local governments. The planning processes involved a development of a sketch plan network model for the three county area. The Council has used this model to simulate the travel demand consequences of alternative regional land use plans which they have developed.

While the Council, unlike NTO's and designated regional Councils of Government, has no statutory powers to prepare transportation plans, it has pioneered in transportation and land use planning through its series of policy simulations, supported by a grant from the Urban Mass Transportation Administration. Copies of studies are available from the Council.

APPENDIX B: QUESTIONNAIRE

Survey of Modeling Practice

City/Region:____________________________________

Name of Interviewee(s)/Title/Telephone/Address

____

____

____

____

Introduction

Cambridge Systematics is the lead consulting firm in a multidisciplinary team, conducting a national demonstration study of the relationships between transportation, land use and air quality at the local level. The study is being conducted for 1,000 Friends of Oregon, a statewide land use advocacy organization, with support from major national foundations and federal agencies.

The purpose of the study is to document the effect which alternative land use patterns have on travel demand and, as a result, on air quality. The study will be complete in the Spring of 1992.

One early element in our work is to summarize the state-of-the-practice in the integration of land use planning/forecasting into transportation travel demand modeling. We are seeking information on the ways in which agencies incorporate land use data or modeling procedures into their forecasts.

We have identified your agency as:

[Whichever Applies:]

- One of the major transportation planning organizations in the country, in terms of the region you serve; [and/or]
- One of the transportation planning organizations in the U.S. working on improving the ways in which land use planning and transportation planning are integrated; [and/or]-

- One of the organizations known to be using an integrated land use and transportation modeling system.

I'd like to ask you a series of questions about your current work. The interview should take approximately 20-30 minutes, Do you have any questions before we begin?

1. Concerning Land Use Forecasting

    1. How are land use forecasts developed for your metropolitan area?

        1. Consensus
        2. Projections of existing plans
        3. To reflect build-out of current zoning
        4. Model results

Explain:____

____

____

____

____

____

2. What agencies or organizations are involved?

____

____

____

____

____

3. To what extent are the following types of models used as part of the land use forecasting process?

- Locally developed economic forecasting techniques.
- Regional economic forecasting models (e.g., REMI, DRI, Wharton, Woods & Poole)
- Lowry-type allocation model, (e.g., DRAM/EMPAL)
- Integrated Models, (e.g., ITLUP)
- Others.

Explain:____

____

4. Does the existing or projected future transportation system have any impact on future land use forecasts?

- None.
- Informal only
- Formally, via the following models. (Explain:)

2. Concerning Transportation Models
    1. I'd like to get information on the types of variables used in your travel modeling system. I think the easiest way would be for me to fax a page for you to fill out. Is that all right with you?
        1. What is your fax number?
    2. Also, do you have written documentation/descriptions of your modeling system? Can I obtain a copy?
3. Concerning Public Policy
    1. What has been the most important current/recent (last five years) public policy issue addressed by your agency which has required the use of land use/transportation modeling? (e.g., regional transportation plans, development reviews, regional land use plans, capital programming, etc.)
    2. Please give a brief description of this major issue or group of issues (i.e., problem statement, techniques used, organizations involved, results.)

____

4. Relationship to Air Quality Planning

    1. Are you familiar with your region's air quality planning work? ______

    2. (If yes), have alternative land use patterns been considered as a policy to bring about compliance with air quality standards for Your region? If so, please describe the process.

____

____

____

5. Concerning Modeling Needs

    1. What major gaps do you see in current land use modeling practice in your region (i.e., modeling tools, data availability, etc.)?

____

____

____

    2. Have you considered alternatives to fill these gaps? If so, what policies/ tools/models/data?

____

____

____

6. Other/Conclusions

    1. Have you any other remarks or observations you would like to make concerning the transportation/land use/air quality planning in your region?

____

____

____

TO: ____________________________________

____

FAX: ____________________________________

DATE: ____

PROJECT NO.: 29105.02

NUMBER OF PAGES: 2

If there are any problems with this transmission, please call us at (617) 354-0167.

Re: Transportation/Land Use/Air Quality Survey

---

1. Please indicate on the matrix on the next page, the types of variables which affect travel predictions for your area. This can be done by putting an X in all boxes which represent a direct relationship between a variable type and the aspects of travel predicted by a particular transportation model. Note that direct relationships can be due to any of the following conditions:

- The value of a variable enters a predictive equation directly.
- The value of a variable is used to define a category for which unique model parameters and/or predictive equations exist.
- The value of a variable is used to define whether or not a class of transportation options is available for a particular market segment.

The following is an example of a relationship which is **not direct**:

Work trips are distributed using a gravity model which requires the outputs of a trip production model expressed as trips = (trips per worker) * (number of workers). Work trip **distribution** is **not directly related** to the number of workers. If you use standard gravity models for trip distribution, then trip distribution will not normally be a function of any of the variable types listed. In addition, the standard UTPS or UTPS-type system does not use any of these variables in the highway assignment and transit assignment steps. In these cases, the corresponding columns of the matrix may be disregarded.

2. Add other major models, such as auto ownership, in an empty column of the matrix and complete the appropriate entries for the variable types listed in the matrix.

3. Please return the next page to us by fax as soon as possible. Our fax number is (617) 354-1542.

Variables Used Directly in the ______ Model System Type of System______

Variable Types	Trip Productions	Trip Attractions	Trip Distribution	Mode Choice	Highway Assignment	Transit Assignment	Travel by Time of Day		
Population									
Households									
Employment									
Other land use variables (specify)									
Income									
Life cycle categories									
Auto ownership									
Workers or labor force									
Other demographic characteristics (specify)									
Parking limitations									
Parking costs									

ACKNOWLEDGMENTS

About 1000 Friends of Oregon

1000 Friends of Oregon is a non-Profit public service organization formed in 1975 to protect Oregon's quality of life through the conservation of farm and forest lands, the protection of natural and historic resources, and the promotion of more livable cities. The organization pursues these goals through research, public education, and no-cost citizen legal assistance. 1000 Friends is supported by its membership and tax-deductible contributions.

1000 Friends also provides staff support for the National Growth Management Leadership Project, a coalition of conservation organizations from 18 states working on growth management and land use policy.

1000 Friends Project Staff

Keith A. Bartholomew	Project Coordinator
Mary Kyle McCurdy	Assistant Coordinator
Scot Siegel	Project Assistant

Project Advisory Committees

"Making the Land Use, Transportation, Air Quality Connection" has been made possible, in part, by the contributions of time and expertise from the members of the study's three advisory committees.

National Technical Advisory Committee

The National Technical Advisory Committee directs the general course of research for the project.

Jeffrey M. Zupan, Chair	Transportation Consultant, Chestnut Ridge, New York
George M. Crandall	Principal, Fletcher, Farr, Ayotte, Portland, Oregon
Elizabeth Deakin	Associate Professor, University of California at Berkeley
Michael A. Replogle	Transportation Coordinator, The Maryland-National Capital Park and Planning Commission, Silver Spring, Maryland
William Schroeer	Energy Analyst, Air & Energy Policy Division, U.S. Environmental Protection Agency, Washington, D.C.
Robert Yuhnke	Staff Attorney, Environmental Defense Fund, Boulder, Colorado

Policy Advisory Committee

Composed of local political, business, and citizen leaders, the Policy Advisory Committee provides general guidance on the feasibility of policy alternatives.

Meeky Blizzard	Executive Director, Sensible Transportation Options for People
William Blosser	Chair, Oregon Land Conservation and Development Commission; Chair, State Agency Council on Growth in the Portland Metropolitan Area

Earl Blumenauer	Commissioner, City of Portland
Rex Burkholder	Portland Area Bicycle Coalition
Jane Cease	Administrator, Oregon Motor Vehicles Division
John Charles	Executive Director, Oregon Environmental Council
Rena Cusma	Executive Officer, Metropolitan Service District
James Gardner	Councilor, Metropolitan Service District
Fred Hansen	Director, Oregon Department of Environmental Quality
Richard Hohnbaum	Mayor, City of Sherwood
Michael Hollern	Chair, Oregon Transportation Commission
Jim Howell	President, Citizens for Better Transit, Inc.
Vera Katz	Representative, Oregon Legislative Assembly
Patricia Kliewer	Citizen Participation Organization 010, Washington County
Susan McLain	Councilor, Metropolitan Service District
Gussie McRobert	Mayor, City of Gresham
Linda Peters	Commissioner, Washington County Board of Commissioners
John Russell	President, Russell Development Company
James Standring	President, Westland Industries, Inc.; President, Home Builders Association of Metropolitan Portland
Thomas Walsh	General Manager, Tri-County Metropolitan Transportation District of Oregon

Local Technical Advisory Committee

The Local Technical Advisory Committee consists of technical staff from local governments and state agencies, and provides local technical assistance and information.

G. B. Arrington	Director of Long Range and Strategic Planning, Tri-County Metropolitan Transportation District of Oregon
Richard Bolen	Regional Planning Supervisor, Metropolitan Service District
Robert Brannan	Project Manager, Parsons, Brinckerhoff, Quade & Douglas

Richard Carson	Director of Planning and Development, Metropolitan Service District
Robert Cortright	Transportation Planner, Oregon Department of Land Conservation and Development
Andy Cotugno	Director of Transportation, Metropolitan Service District
Brent Curtis	Planning Manager, Washington County Department of Land Use and Transportation
Steve Dotterer	Chief Planner, Office of Transportation, City of Portland
Barrow Emerson	Manager, Regional Rail Program, Office of Transportation, City of Portland
Brian Gregor	Senior Transportation Planner, Oregon Department of Transportation
Charles Hales	Vice President, Home Builders Association of Metropolitan Portland
James N. P. Hendryx	Planning Manager, City of Beaverton
Merlyn Hough	Air Quality Division, Department of Environmental Quality
Keith Lawton	Technical Manager, Metropolitan Service District
Doug McClain	Principal Planner, Clackamas County
Scott Pemble	Transportation Planning Supervisor, Acting Director of Planning and Development, Multnomah County
Robin McArthur-Phillips	Coordinator, State Agency Council on Growth in the Portland Metropolitan Area
Sam Sadler	Transportation Energy Specialist, Oregon Department of Energy
Ethan Seltzer	Senior Regional Planner, Metropolitan Service District
Edward Spence	Plan/Program Manager, Region 1, Oregon Department of Transportation
Robert E. Stacey, Jr.	Director, Planning Bureau, City of Portland
Ron Weinman	Principal Transportation Planner, Clackamas County
Mike Wert	Special Projects Manager, Oregon Department of Transportation

About the Authors of this Volume

Cambridge Systematics, Inc.

Cambridge Systematics provides planning and management services in the areas of transportation, management information systems, economic development, energy and telecommunications. Since its formation in 1972, the firm has gained a national reputation for applying state-of-the-art analytic techniques to complex problems, and developing innovative, practical solutions for clients.

Principals of Cambridge Systematics working on this project are Samuel Seskin, Earl Ruiter and John Suhrbier.

Hague Consulting Group

Hague Consulting Group, located in The Hague, Netherlands, is known for its application of travel demand forecasting models worldwide. In The Netherlands, the firm is participating in a national transportation plan, applying an integrated land use model and other analytic tools to predicting travel demand.

(1) 1/ See Webster, Bly and Paufley, Urban Land-Use and Transport Interaction, Avebury, 1988.

(2) 1/ See for example: JHK and Associates, Travel Characteristics at Large-Scale Suburban Activity Centers, NCHRP Report 323, Washington, D.C., 1989.

(3) 2/ Boris S. Pushkarev and Jeffrey Zupan, Public transportation and Land Use Policy, Indiana University Press, Bloomington, 1977.

(4) 3/ Robert Cervero, America's Urban Centers: A Study of the Land Use Transportation Link, Unwin Hyman, Boston, 1989.

(5) 4/ The Pedestrian Pocket Book, Princeton Architectural Press, 1989.