MAKING THE LAND USE, TRANSPORTATION, AIR QUALITY CONNECTION - MODELING MODIFICATIONS, VOLUME 4

CAMBRIDGE SYSTEMATICS, INC., S.H. PUTMAN ASSOCIATES, CALTHORPE ASSOCIATES, WITH PARSONS BRINCKERHOFF QUADE AND DOUGLAS, INC.

NOVEMBER 1992

Sponsored by: The Energy Foundation, The Nathan Cummings Foundation, Federal Highway Administration, United States Environmental Protection Agency

Additional funding provided by: Surdna Foundation, Inc., The Joyce Foundation, ARCO Foundation, Lincoln Institute of Land Policy, National Endowment for the Arts, Tri-County Metropolitan Transportation District of Oregon, Metropolitan Service District, Portland General Electric Company, Home Builders Association of Metropolitan Portland, Pacific Development, Inc., Key Bank of Oregon, David Evans & Associates, Inc., Kurt Koehler

ABSTRACT

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

- automobile dependency;
- mobility;
- air quality;
- energy consumption; and
- sense of community.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS (not available at this time)

INTRODUCTION

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

- automobile dependency;
- mobility;
- air quality;
- energy consumption; and
- sense of community.

Using the proposed Western Bypass freeway around the Portland, Oregon metropolitan region as a case study, LUTRAQ has (1) identified alternative land use development patterns that reduce travel demand and increase the use of alternative travel modes, and (2) developed 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 (1) identified the international state-of-the-art of integrated land use/transportation modeling; (2) determined current modeling practices in U.S. metropolitan areas; and (3) evaluated the modeling system in place for the LUTRAQ study area.

Task B. Analyze the Base Case
The project team established current land use and transportation opportunities and constraints in the study area.

Task C. Develop the LUTRAQ Alternative Package
The project team is currently establishing two alternatives to freeway construction, each 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 has improved the modeling system in the study area to assure accurate measurement of the alternatives developed in Task C.

Task E. Test the Alternatives
Using the modeling improvements from Task D, the team is analyzing a no-action alternative, the freeway alternative, and the LUTRAQ alternative (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 LUTRAQ 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	Cambridge Systematics, Inc., Calthorpe Associates and Parsons Brinckerhoff
3A	Market Research	Market Perspectives and Hébert/Smolkin Associates, Inc.
4	Model Modifications	Cambridge Systematics, Inc., S.H. Putman and Associates and Parsons Brinckerhoff
5	Analysis of Alternatives	Cambridge Systematics, Inc., Calthorpe Associates and Parsons Brinckerhoff
6	Implementation	Cambridge Systematics, Inc., Calthorpe Associates and Parsons Brinckerhoff
7	Final Report	Cambridge Systematics, Inc., Calthorpe Associates and Parsons Brinckerhoff
8	Technical Appendix	Cambridge Systematics, Inc., Calthorpe Associates and Parsons Brinckerhoff

Volume List

SUMMARY

This volume summarizes the work undertaken by the LUTRAQ project team and the Metropolitan Service District (Metro) to enhance the Portland area land use and transportation forecasting and analysis procedures. Efforts included enhancement of the transportation models, and integration of the transportation models with land use models.

Travel Model Enhancements

The Portland travel forecasting system, while one of the most advanced in use in the U.S., had deficiencies that limited its usefulness in evaluating the effects of land use/transportation strategies. The project team, in cooperation with Metro, developed several enhancements to the models to alleviate the problems.

Four models - auto ownership, destination choice, pre-mode choice, and mode choice - were revised. The auto ownership model predicts levels of car ownership (0, 1, 2, 3+) at the household level. Its outputs are important inputs into the trip generation, pre-mode choice, and mode choice of the trip productions estimated in the trip generation model. Destination choice therefore models for home-based trip purposes. Destination choice, or trip distribution, determines the attraction ends implies a trip length distribution as it estimates the number of trips from each origin zone to the other zones in the metropolitan area. The pre-mode choice model estimates the percentage of trips using the walk or bicycle modes for each origin-destination zone pair. The mode choice model determines how many vehicular trips use the auto mode and how many use transit. For home-based work trips, the split between single occupant auto and carpool and between auto and walk access to transit is also estimated.

The primary revisions to the auto ownership, pre-mode choice, and mode choice models were the additions of variables to make the models more sensitive to variations in the heterogeneity of development (the degree to which land uses are mixed), and the quality of the pedestrian environment. Regarding land use density and mix (heterogeneity), the consultants tested several forms of variables in the model structure. The most useful, and statistically reliable, was a measure of retail density. Specifically, the number of retail jobs within one mile of the center point (centroid) of a traffic analysis zone proved to be statistically significant in explaining auto ownership and pre-mode choice.

To address the quality of the pedestrian environment, a new variable, called the "pedestrian environment factor" (PEF), was created. The measure represents a composite measure of the "pedestrian friendliness" of each of the analysis zones in the model system. It was developed in acknowledgment of the fact that a number of factors at the neighborhood and street level affect individuals' willingness and ability to choose the walk mode for various trip purposes. As developed by the Metro staff in consultation with the consulting team, the PEF consists of an assessment of each zone on four different parameters:

- Ease of street crossings
- Sidewalk continuity
- Local street characteristics (grid versus cul-de-sac)
- Topography

In addition to the above model improvements, the destination choice model was improved by changing the computation of intrazonal travel time, thereby enhancing the model's ability to calculate intrazonal trips.

Overall, the model enhancements were successful in improving the ability of the forecasting system to estimate demand over wide ranges of development densities and pedestrian environments. The model improvements were particularly effective in improving the ability to estimate the effects of development density and pedestrian environment on the pre-mode choice (walk/bike vs. vehicle) for home-based trips.

Land Use Model

A significant part of the 1000 Friends of Oregon LUTRAQ project involves the integration of location and land use forecasting procedures with the transportation forecasting procedures currently in use for the region. To accomplish this the consultant recommended making use of the EMPAL and DRAM models of employment and residential location and land consumption, developed by S. H. Putman Associates. These models were integrated into the Metro transportation modeling process.

Calibration of the DRAM (residential) model with 100 zone 1990 data for the Portland region was successful. The fits achieved were quite reasonable. That some of the household types yielded slightly lower than expected fit levels probably reflects the rather homogeneous character of many, though of course not all, of the region's residential areas. The signs and magnitudes of the parameters were consistent with prior tests and applications of the DRAM model to data sets for other regions.

Calibration of the EMPAL (employment) location model with 1985 and 1990 data for the Portland region was successful. The fits achieved were quite good. The signs and magnitudes of the parameters were consistent with prior tests and applications of the EMPAL model to data sets for other ions.

Based on analysis of the results presented in this report, the DRAM and EMPAL models will work properly in the Portland region. Further work is anticipated by Metro to develop an integrated set of feedback loops that will link all of the land use and transportation models.

Installation and calibration of these models makes possible a more accurate forecast of the interactive effects of land use decisions and transportation investments. Using these tools, the LUTRAQ team will test the ways in which different mixes of transportation investments (transit and highway) affect development after the opening of the facilities. This will be a dramatic departure from transportation planning practice, which currently plans facilities to meet forecast travel demand, without considering the influence of the facility on the magnitude and spatial location of travel demand after facility completion.

CHAPTER 1: TRANSPORTATION MODEL ENHANCEMENTS

Introduction

This chapter summarizes the enhancements, made to the Metropolitan Service District ("Metro") transportation modeling system for the LUTRAQ project. These enhancements incorporate development density and pedestrian environment characteristics of traffic analysis zones into the models of auto ownership, destination choice, and mode choice. They also improve the modeling system's capabilities for the prediction of short trips and walk and transit trips. These aspects of the modeling system are critical in the analysis the land use and transportation elements of the LUTRAQ alternative.

Volume 1 of the LUTRAQ study reports provides a detailed description of the Service currently used to model travel demand in the Portland area. Although it is one of the most advanced travel forecasting systems in the United States, Volume 1 identifies two major shortcomings of the model which limit its usefulness in evaluating land use/transportation strategies. These are:

- The lack of a formal feedback mechanism from the transportation modeling system to the land use forecasting process; and
- A lack of sensitivity to variations in urban design that could reduce dependence on the automobile.

The first deficiency is addressed by the introduction of the DRAM/EMPAL land use allocation model into the forecasting system, which is discussed in Chapter 2 of this volume. The model enhancements described in this chapter are designed to address the second deficiency listed above.

Overview of the Portland Modeling System

This section briefly summarizes the Portland model system so that the model revisions described later can be understood in the context of the entire process. The description focuses on the particular models enhanced by the LUTRAQ project.

Figure 1 shows the models that comprise the Portland system and their interrelationships. Four models among those shown in Figure 1 - auto ownership, destination choice, pre-mode choice, and mode choice - are those that could be expected to be affected by such features as development density and heterogeneity, a favorable pedestrian environment, and good transit service. As the figure shows, the results of each model can affect previous models through feedback mechanisms.

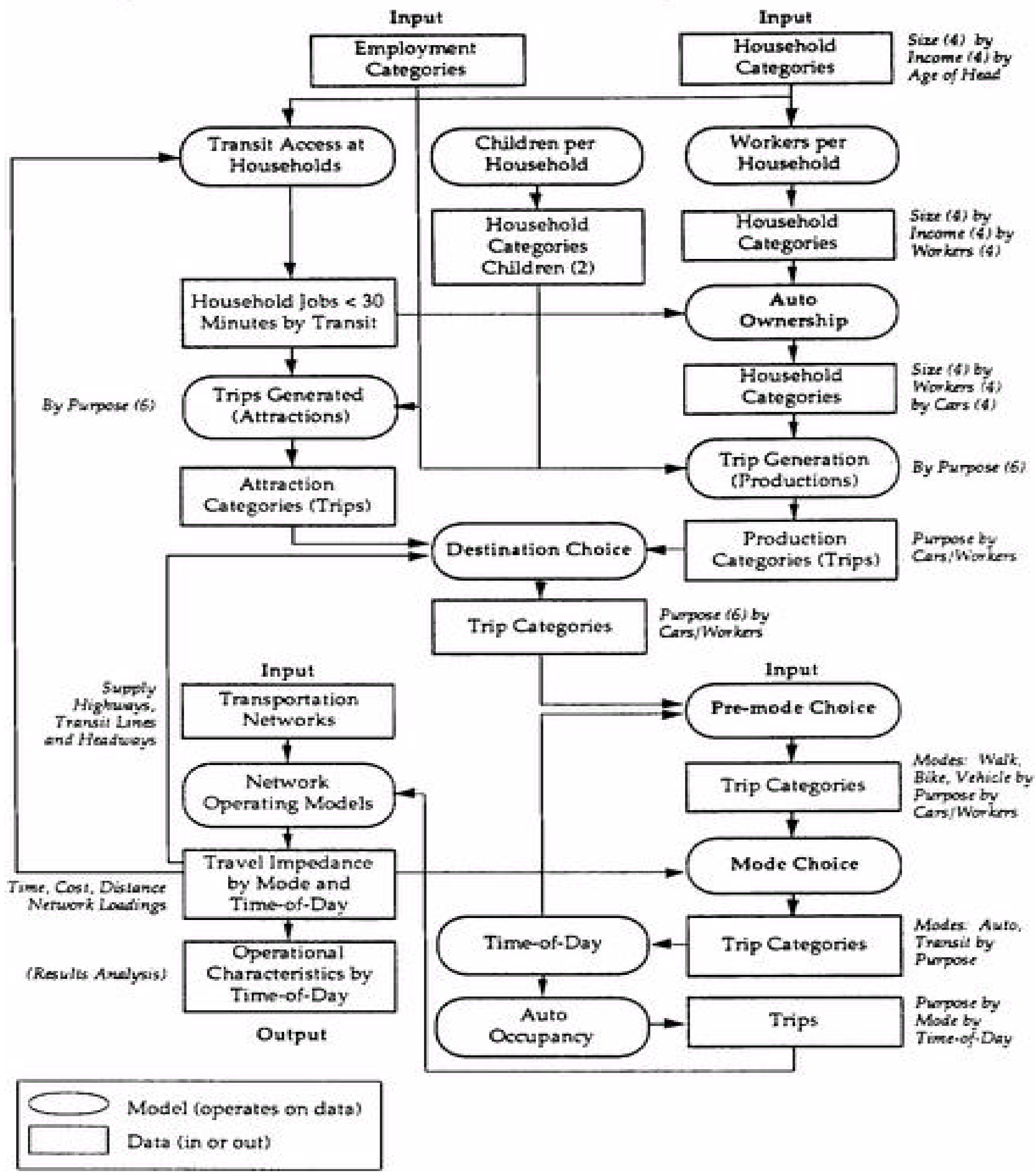
The auto ownership model predicts levels of car ownership (0, 1, 2, 3+) at the household level. Its outputs are important inputs into the trip generation, pre-mode choice, and mode choice models for home-based trip purposes.

Destination choice, or trip distribution, determines the attraction ends of the trip productions estimated in the trip generation model. The destination choice model therefore produces a trip length distribution as it estimates the number of trips from each origin zone to the other zones in the metropolitan area.

The pre-mode choice model estimates the percentage of trips using the walk or bicycle modes for each origin-destination zone pair. There are currently insufficient data to distinguish between the two modes, and so they are treated as a single mode in the Portland model.

The mode choice model determines how many vehicular trips use the auto mode and how many use transit. For home-based work trips, the split between single occupant auto and carpool and between auto and walk access to transit is also estimated.

Figure 1. Portland Travel Forecasting Model Structure



Model Enhancement Strategy

The general strategy for revising the models in the context of the LUTRAQ study was to test new variables that reflect residential and employment density and heterogeneity, and the quality of the pedestrian environment. In addition, the forms of certain existing variables were changed. This section discusses the actual model enhancements that were tested, describes the final "enhanced" models, and compares the results to the original models.

To eliminate the effects of traffic analysis zone boundaries, density was defined as the number of employees or households within one mile. (Different unit areas for the density measures were also tested; for example, employment within one half mile instead of one mile. None of these measures proved to be statistically significant.) Since geographic coding of data was done at the zonal level, it was necessary to measure the one mile radius from the centroid of the zone in which the household (for which auto ownership was to be estimated) was located; employees and other households were assumed to be located at their zone centroids. For the majority of zones, which are small, this was not a major problem; for large zones, the potential for significant error was somewhat offset by the fact that the large zones are predominantly of low density.

One measure of the quality of a travel demand model is how well it replicates observed behavior. In the case of the Portland model, the model results can be compared to the survey data on which it is estimated. Data can be summarized over different values of any variable for which survey information is available. For the LUTRAQ study, it was logical to summarize data by levels of development density and the quality of the pedestrian environment. Metro provided the data comparisons shown in this report.

It is important to recognize that replication of survey data is not the only measure of the quality of the models; the ability to predict travel behavior under conditions that may be different than the base case is even more critical.

Auto Ownership Model

The original auto ownership model was formulated as a logit model with the following utility functions:

For 0-car households:
U = 5.125 - 0.918 HHSIZE - 1.442 WORKERCL
- 1.580 INCOMECL
+ 0.0000174 TOTAL30T
For 1-car households:
U = 5.844 - 0.727 HHSIZE - 1.076 WORKERCL
- 0.892 INCOMECL
+ 0.0000084 TOTAL30T
For 2-car households:
U = 2.871 - 0.167 HHSIZE - 0.658 WORKERCL
- 0.215 INCOMECL
+ 0.0000041 TOTAL30T
For 3-car households:
U = 0

where:

U =	utility
HHSIZE =	number of persons in household
WORKERCL =	number of persons in household
INCOMECL =	1 if household income < $15,000
	2 if household income > $1 5,000 and

	< $25,000 3 if household income > $25,000 and < $35,000 4 if household income > $35,000
TOTAL30T =	number of employees within 30 minutes of travel time via the transit mode

These equations show that auto ownership increases with higher levels of income, workers, and persons per household.

The primary goals for the revision of the auto ownership model were to incorporate the effects of development density and heterogeneity, and the pedestrian environment. Since the pedestrian environment variable was developed later in the model improvement process, the first task was to determine how the effects of development density and heterogeneity could be incorporated.

The consultant team and Metro tested several measures of density in the auto ownership model including retail employment, non-retail employment, total employment, and households. These were tested separately and in combination with each other where appropriate. The conclusion is that employment density is a significant factor in auto ownership, and that retail employment density appears to be the most significant indicator of employment density for this model. It is interesting to note that the use of this variable did not render insignificant the transit accessibility variable TOTAL30T, which is also to some extent a density measure. Residential density did not prove to be a significant indicator of auto ownership levels. This seems reasonable since the decision of how many autos to own is made at the household level, and the locations of other households would probably not affect the decision of auto ownership level.

The consultants also tested some combined measures of development density and heterogeneity in the auto ownership model, including residential versus commercial (measured by employment) and retail versus non-retail measures. These measures failed to be significant indicators of auto ownership and weakened the effectiveness of the density measure. The measures failed apparently because of the irrelevance of residential density and the relatively high correlation between retail and non-retail employment densities.

Other measures of transit accessibility were tested as alternatives to TOTAL30T. These included the inverse of out-of-vehicle time and total employment within 45 minutes of transit travel time. TOTAL30T remained the most significant variable, and it was retained in the model.

A variable measuring the quality of the pedestrian environment, called the "pedestrian environment factor" (PEF), was created. The measure represents a composite measure of the "pedestrian friendliness" of each of the analysis zones in the model system. It was developed in acknowledgment of the fact that a number of factors at the neighborhood and street level affect individuals' willingness and ability to choose the walk mode for various trip purposes.

As developed by the Metro staff in consultation with the consulting team, the pedestrian environmental factor (PEF) consists of an assessment of each zone on four different parameters. They are the following:

- Ease of street crossings
- Sidewalk continuity
- Local street characteristics (grid versus cul-de-sac)
- Topography

Several measures were discussed and evaluated in terms of their ability to distinguish each of the zones on these parameters. The approaches varied from highly quantitative to qualitative. Data and time constraints obliged the use of relatively qualitative approaches, described below.

For estimating ease of street crossings in each of the zones, staff identified key intersections and evaluated both their width, extent of signalization and traffic volumes. Regarding sidewalk continuity, staff judged the extensiveness of sidewalks on principal arterials served or likely to be served in the future by transit. Secondary attention was paid to- the extent of sidewalks on collectors. For the characteristics of the street systems, staff estimated the extent of grid street patterns throughout each of the zones. They also examined the fineness of the grid. For topographic considerations, staff evaluated zones in terms of the extensiveness of sloping terrain and the steepness of these slopes.

On each of these four parameters, staff assigned a value to each zone, ranging from I to 3. Values for each of the parameters were summed, leading to a ranking for each zone ranging from 4 to 12. Four represented the lowest possible score in terms of overall pedestrian environmental conditions. A score of 12 represented the highest possible score.

Four different staff completed this exercise and compared their results, in order to enhance the objectivity of the analysis. Results were compared and staff modified some zonal scores on specific parameters to reflect a consensus reached on their characteristics. This simplified Delphi process resulted in consensus on rankings for the entire network of zones.

The PEF proved to be a significant variable in the auto ownership model. This implies that in an area where walk trips can be more easily made, the need for an automobile is diminished.

One other revision was made to the auto ownership model. Rather than use a single "income class" variable, binary variables were used to indicate to which income class the household belonged. This improved the sensitivity of the model to income. In the original model, for example, the difference in the utility of owning no automobiles was the same between the two highest classes as between the two lowest. The use of the binary variables corrected this problem.

The final formulation of the revised auto ownership model has the following utility functions:

For 0-car households:

U = -1.684 - 0.881 HHSIZE - 1.452 WORKERCL + 3.255 INCOM1 + 1.942 INCOM2 + 0.000220 RET1M + 0.00001063 TOTAL30T + 0.2095 PEF

For 1-car households:

U = 1.497 - 0.720 HHSIZE - 1.065 WORKERCL + 2.259 INCOM1 + 1.944 INCOM2 + 1.033 INCOM3 + 0.000132 RET1M + O.00000615 TOTAL30T + 0.0902 PEF

For 2-car households:

U = 1.619 - 0.141 HHSIZE - 0.660 WORKERCL + 0.377 INCOM1 + 0.555 INCOM2 + 0.478 INCOM3 + 0.000060 RET1M + 0.00000334 TOTAL30T + 0,0337 PEF

For 3-car households:

U = O

where:

INCOM1 =	1 if INCOMECL = 1, 0 otherwise
INCOM2 =	1 if INCOMECL = 2, 0 otherwise
INCOM3 =	1 if INCOMECL = 3, 0 otherwise
RET1M =	number of retail employees located within one mile
PEF =	pedestrian environment factor, as described above
	and other variables defined as in the original model

The revised model continues to indicate the positive correlation between auto ownership and income, workers, and persons per household. Auto ownership declines as retail intensity increases or the pedestrian environment improves.

Table 1 shows the results of the comparison of both the original and revised model with the survey data. This table shows that both the original and revised versions of the model predict the number of households of each auto ownership class very well over the entire universe of households. The fit between both models and the survey data continues to hold over different levels of employment density. The revised model seems to perform slightly better for the most pedestrian friendly and least pedestrian friendly areas, especially in predicting the number of zero-car households. These differences, however, are not great.

Table 1. Auto Ownership Model Results

		Survey	Original Model	Enhanced Model
All households	0 car	5.0%	5.1%	5.0%
	1 car	29.6%	30.5%	29.6%
	2 car	44.8%	44.0%	44.8%
	3+ car	20.6%	20.4%	20.6%
By retail employment density quartiles (lowest to highest)				
Quartile 1	0 car	1.6%	2.0%	1.5%
	1 car	19.4%	23.8%	21.9%
	2 car	50.1%	48.2%	50.0%
	3+ car	28.9%	25.9%	26.7%
Quartile 2	0 car	2.1%	2.9%	2.7%
	1 car	28.1%	27.4%	26.0%
	2 car	47.9%	46.8%	48.2%
	3+ car	21.8%	22.9%	23.2%
Quartile 3	0 car	4.4%	5.0%	4.8%
	1 car	34.0%	32.9%	33.0%
	2 car	43.8%	43.7%	44.0%
	3+ car	17.8%	18.3%	18.2%
Quartile 4	0 car	12.3%	11.0%	11.7%
	1 car	39.2%	39.1%	39.2%
	2 car	36.3%	36.5%	36.0%
	3+ car	12.2%	13.3%	13.1%
By pedestrian environment factor levels (lowest to highest)				
<6	0 car	1.5%	2.4%	1.7%
	1 car	24.2%	26.2%	24.1%
	2 car	48.3%	47.4%	49.4%
	3+ car	25.9%	24.0%	24.7%
<7	0 car	2.4%	2.6%	2.4%
	1 car	23.8%	26.7%	26.0%
	2 car	50.9%	46.3%	46.7%
	3+ car	22.8%	24.3%	24.9%
<10	0 car	7.3%	6.8%	6.8%
	1 car	36.6%	35.1%	35.6%
	2 car	40.9%	41.3%	41.1%
	3+ car	15.2%	16.9%	16.6%
<12	0 car	12.7%	11.5%	12.8%
	1 car	38.8%	38.2%	39.0%
	2 car	36.5%	37.4%	36.0%
	3+ car	12.0%	13.0%	12.2%

Destination Choice Model

The destination choice model is formulated as a logit model. The original utility functions for each origin zone i were specified as follows:

Home-based work: U = ln ATTR(J) - 0.175 T(ij) + 0.0009 T(ij)2
Home-based school: U = ln ATTR(J) - 0.60 T(ij) + 0.012 T(ij)2
Home-based college: U = ln ATTR(J) - 0.45 T(ij) + 0.002 T(ij)2
Home-based other: U = ln ATTR(I) - 0.39 T(ij) + 0.003 T(ij)2
Non-home-based work: U = ln ATTR(I) - 0.27 T(ij) + 0.002 T(ij)2

Non-home-based nonwork: U = ln ATTR(J) - 0.35 T(ij)

where:

U =	utility
ATTR(j) =	number of attractions at (destination) zone j
T(ij) =	travel time from origin zone i to destination zone j

The assumption for intrazonal travel time (T(ii) for all i) was 95% of the travel time to the nearest neighbor zone. The equations show that the number of trips to a zone increases as the number of suburban, southwest, southeast, east city, east suburban, west city, and Clark County (attractions in the zone goes up and decreases as the travel time from the origin zone becomes greater.

For calibration purposes, Metro aggregates the zones in the study area to eight districts: CBD, west Washington). The district-to-district distribution from the survey data, expanded to the number of trips made, is the basis for the calibration of the study area trip tables. Factors for certain district-to-district interchanges - those crossing the Columbia or Willamette Rivers and those to or from downtown - were computed based on the ratio between the implied survey distribution and the initial (uncalibrated) model results. The trip distribution, at least on the district level, therefore matches the observed distribution for the base year.

The destination choice model is entirely dependent on the definition of the zone boundaries. Because of this unique characteristic of the model and the fact that only a small sample of the choice set of destination zones is actually used in model estimation, it would be very, difficult to estimate the model with such measures as development density and quality of pedestrian environment. It is also unclear what effect these measures should have by themselves; for nearby zones, such variables might attract more trips but for more distant zones, fewer trips might be attracted since these zones would tend to attract more intrazonal and short distance trips.

The underestimation of short and intrazonal trips in the original destination choice model was the primary focus of the model revisions. Several methods were tested for the intrazonal travel times to be used in the model, including changing the percentage of the time to the nearest neighbor zone to a lower number, basing the travel time on the land area of the zone, and using a measure of the shape of the zone. Only changing the percentage of the nearest neighbor travel time proved successful, and the percentage was changed to 73%.

The consultant team and Metro also attempted to develop an intrazonal choice model, which would estimate the percentage of trips produced in a zone that remained in the zone. The destination choice model would then be estimated only for trips that leave the zone. Unfortunately, the zone system that the survey data were geocoded for does not match that used for the Western Bypass Study and the LUTRAQ project, and the intrazonal choice model was not transferable to the different zone system.

Another possible way of obtaining more accurate estimates of short trips would be to change the model estimation method. Currently, the large number of alternatives (destination zones) in the destination choice model for each origin zone requires that the choice set for each observation in the survey data set be limited to a sample of destination zones. For most observations, the origin zone itself and most nearby zones would not be possible destinations in the sample. "Stratifying" the sample to ensure that more nearby zones are included would result in more short trips being modeled. The development of the sample stratification procedure, however, was deemed too time consuming to be practical in the model enhancement process.

The only model revision for the destination choice model is therefore the change in the intrazonal travel time assumption.

Because of the huge number of possible zone-to-zone origin-destination choices, the actual base trip table is not known at the zone-to-zone level and cannot be inferred from the survey data. Alternative measures of how well the model replicates existing conditions must be used. The trip length frequency distribution from the model, for example, can be compared to the survey results. The distributions for the survey data and for the original and revised model trip tables do not differ very much, which is not surprising considering the minor nature of the model revision.

Pre-Mode Choice Model

Numerous opportunities for the enhancement of the pre-mode choice model were apparent. In particular, the quality of the pedestrian environment should be an especially important factor in the decision whether to walk/bicycle or drive/use transit.

The consultants did not revise the pre-mode choice and mode choice models for the home-based school and home-based college purposes. Home-based school trip mode choices are not easily modeled due to a the unique characteristics of these trips such as the lack of destination options, the high number of linked trips, and disparities in transportation supply (school bus, regular transit service) across the study area. The survey data are not sufficient for a more detailed model than the simple cross-classification mode choice (there is no pre-mode choice model) procedure currently used by Metro for home-based school trips. Home-based college trips represent less than 3% of trips in the Portland area and, since college locations would not be affected by the land use alternatives analyzed in the LUTRAQ study, were not considered in the model revision procedure.

In the pre-mode choice model, Metro sets a maximum distance for walk/bicycle trips. This maximum is based on the survey data and represents a length greater than that of 95% of walk/bicycle trips for each purpose. These maxima are: five miles for home-based work trips, three miles for home-based other trips, and two miles for non-home based trips. Longer trips are assumed to be made by auto/transit.

The original form of the pre-mode choice model varies by trip purpose. For the home-based trips (work and other), a simple walk/bike percentage is applied (for trips of less than the maximum distance) to zero car households: 18.6% for work trips, 30.8% for other trips. For households which own automobiles, logit models are used with utility functions of the form:

Work trips:

U = 1.299 + 0.718 TDIST - 1.347 VALCAR1 for auto/transit trips
U = 0 for walk/bike trips
Nonwork trips:
U = 2.120 + 0.744 TDIST - 0.732 VALCAR1 - 0.246 VALCAR2 - 0.0000464 RET1M for auto/transit trips
U = 0 for walk bike trips

where:

U =	utility
TDIST =	trip distance
VALCAR1 =	I if household owns <1 car per worker, 0 otherwise
VALCAR2 =	I if household owns 1 car per worker, 0 otherwise
RET1M =	retail employment within one mile of the attraction zone

The utility equations show that longer trips are more likely to be made by automobile or transit and that trips from households without as many cars as workers or to densely developed locations are more likely to be made by walking or bicycling. Note that the pre-mode choice model for home-based other trips originally included a variable representing retail employment density.

For non-home based trips, the logit utility functions for trips of over two miles are:

Non-home based work.
U = 10.487 + 2.169 TDIST - 1.097 ln TOTEMP for auto/transit trips
U = 0 for walk/bike trips
Non-home based nonwork.
U = 6.844 + 0.745 TDIST + 0.160 ln RETEMP - 0.788 ln OTHEMP for auto/transit trips
U = 0 for walk/bike trips

where:

TOTEMP =	total employment in the production zone
RETEMP =	retail employment in the attraction zone
OTHEMP =	nonretail employment in the attraction zone and other variables defined as for home-based trip models

Note that for non-home based trips, the employment variables are not density variables. They are variables defining the size of the production or attraction zone in terms of employment.
For the home-based work model, the consultant team tested measures of development density and the quality of the pedestrian environment. Both proved to be significant indicators of the propensity to walk or ride a bicycle to and from work; either higher density or a better pedestrian environment make a walk/bike trip more likely. Other "VALCAR" variables, measuring the relationship between the number of autos owned and the number of workers in a household, were also tested; VALCAR2, as defined for the home-based other model, was found to be significant.

The home-based other model originally contained a density variable. The pedestrian environment factor was tested and found to be significant; as for home-based trips, a better pedestrian environment increases the probability of a walk/bike trip. Other VALCAR variables were also tested and found to be significant. Since VALCAR0, representing whether the household owns an auto, appears in the revised model, the fixed percentage of walk/bicycle trips for zero car households is not part of the revised pre-mode choice model for home-based other trips.

The revised models have the following utility functions:

Home-based work:
U = 1.717 + 0.705 TDIST - 0.954 VALCAR1 + 0.408 VALCAR2 - 0.0000191 TOT1M - 0.0632 PEF for auto/transit trips
U = O for walk/bike trips
Home-based other:
U = 2.697 + 0.686 TDIST - 2.205 VALCAR0 - 0.600 VALCAR1 - 0.000135 RET1M - 0.0620 PEF for auto/transit trips
U = 0 for walk bike trips
Non-home based work.
U = 3.718 + 1.998 TDIST - 0.0000205 TOT1M - 0.178 PEF for auto/transit trips
U = 0 for walk/bike trips
Non-home based nonwork
U = 3.597 + 0.717 TDIST + 0.000778 RETIM - 0.000142 0THlM - 0.167 PEF for auto/transit trips
U = 0 for walk/bike trips

where:

U =	utility
TDIST =	trip distance
VALCAR0 =	1 if household owns a car, 0 otherwise
VALCAR1 =	1 if household owns <1 car per worker, 0 otherwise
VALCAR2 =	1 if household owns 1 car per worker, 0 otherwise
TOT1M =	total employment within one mile of the attraction zone
RET1M =	retail employment within one mile of the attraction zone
OTH1M =	nonretail employment within one mile of the attraction zone
PEF =	pedestrian environment factor (see definition in section on auto ownership model)

Table 2 shows the comparison between the percentages of walk/bike trips indicated by the travel survey and estimated by both the original and revised models for the purposes for which model revisions were performed. The comparison is shown over ranges of trip distance, employment density, and quality of pedestrian environment. As Table 2 shows, the original model tended to underestimate walk/bike percentages in the most dense and pedestrian friendly zones and to overestimate in the least dense and pedestrian friendly, areas, especially for home-based trips. This occurred because the variables in the original models did not sufficiently account for the effects of these characteristics on mode choice. Adding variables to specifically represent these characteristics corrected this problem; Table 2 demonstrates that the revised model corrects this problem.

Mode Choice Model

Except for the home-based school purpose, the mode choice model uses logit formulations, with the utility functions and set of modes being modeled varying by trip purpose. As in the pre-mode choice model enhancement, the home-based school and college models were not revised.

The utility functions for the original mode choice model are as follows:

Home-based work trips:
U = 5.773 - 0.032 IVTIME - 0.07 WALKTIME - 1.100 COST - 0.102 TDIST - 1.219 VALCAR1 - 0.014 EMPDEN for drive alone trips
U = 3.730 - 0.032 IVTIME - 0.07 WALKTIME - 1.1 00 COST - 0. 1 51 TDIST + 0.089 VALCAR1 - 0.014 EMPDEN - 0.054 WAIT1 + 0.455 MULTWORK for shared ride trips
U = 3.072 - 0.032 IVTIME - 0.07 WALKTIME - 1.100 COST - 0.112 TDIST + 0.712 VALCAR1 - 0.006 EMPDEN - 0.054 WAIT1 - 0.068 WAIT2 + 0.106 HHDEN for transit trips (walk access)
U = - 0.032 IVTIME - 0.07 WALKTIME - 1.100 COST - 0.054 WAIT1 for transit trips (auto access)
Home-based other trips:
U = 2.897 - 0.036 IVTIME - 0.091 OVTIME - 0.266 COST - 0.149 TDIST - 2.584 VALCAR1 - 1.425 VALCAR2 - 0.012 EMPDEN for auto trips
U = - 0.036 IVTIME - 0.091 OVTIME - 0.266 COST - 1.893 WORKHH + 0.598 OLDHEAD for transit trips

Table 2. Pre-Mode Choice Model Results
(Percent Walk/Bike Trips)

	Survey	Original Model	Enhanced Model
Home-Based Work Trips	3.3%	3.1%	3.3%
By trip distance quartiles (shortest to longest)			
1	11.5%	10.8%	11.5%
2	1.7%	1.7%	1.7%
3	0.3%	0.2%	0.2%
4	0.1%	0.0%	0.0%
By employment density quartiles (smallest to largest)			
1	2.1%	2.2%	1.8%
2	1.3%	2.4%	2.1%
3	3.4%	3.1%	2.9%
4	6.7%	4.9%	6.6%
By pedestrian environment levels			
<5	2.1%	2.6%	2.0%
<7	2.0%	2.6%	2.2%
<9	5.6%	3.8%	4.6%
<12	5.3%	4.2%	5.6%
Home-Based Other Trips	3.5%	3.2%	3.5%
By trip distance quartiles (shortest to longest)			
1	10.4%	8.6%	9.9%
2	2.9%	3.6%	3.4%
3	1.0%	1.0%	1.0%
4	0.2%	0.1%	0.1%
By employment density quartiles (smallest to largest)			
1	1.4%	2.1%	1.6%
2	1.8%	3.2%	2.6%
3	3.6%	3.8%	3.7%
4	7.6%	4.0%	6.5%
By pedestrian environment levels			
<5	2.0%	2.5%	1.7%
<7	1.6%	2.8%	2.2%
<10	5.1%	3.8%	4.6%
<12	7.7%	4.7%	7.5%
Non-Home Based Work Trips	2.1%	2.1%	2.1%
By trip distance quartiles (shortest to longest)			
1	8.2%	8.2%	8.2%
2	0.4%	0.3%	0.4%
3	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%
By employment density quartiles (smallest to largest)			
1	0.4%	0.3%	0.3%
2	0.3%	0.5%	0.5%
3	0.6%	1.2%	0.9%
4	7.6%	6.8%	7.1%
By pedestrian environment levels			
<6	0.2%	0.5%	0.4%
<9	0.6%	0.9%	0.9%
<11	4.1%	2.7%	2.9%
<12	5.1%	6.2%	6.3%
Non-Home Based Other Trips	3.5%	3.6%	3.5%
By trip distance quartiles (shortest to longest)			
1	10.0%	10.0%	10.0%
2	2.9%	3.4%	3.1%
3	1.3%	1.0%	1.1%
4	0.2%	0.1%	0.1%
By employment density quartiles (smallest to largest)			
1	1.4%	2.0%	1.9%
2	2.7%	2.3%	2.2%
3	1.8%	2.1%	1.6%
4	8.6%	8.2%	8.7%
By pedestrian environment levels			
<5	1.5%	2.6%	2.3%
<7	1.2%	2.1%	1.8%
<10	3.3%	3.1%	3.3%
<12	7.9%	6.6%	6.6%

Non-home based work trips:

U = 3.797 - 0.134 OVTIME - 0.101 TDIST - 0.207 ln PTOT1M for auto trips

U = - 0.134 OVTIME for transit trips

Non-home based other trips:

U = 5.100 - 0.1490 VTIME - 0.242TDIST - 0.304 ln ATOT1M for auto trips

U = -0.149 OVTIME for transit trips

where:

U =	utility
TDIST =	trip distance (miles)
VALCAR1 =	1 if household owns <1 car per worker, 0 otherwise
VALCAR2 =	1 if household owns 1 car per worker, 0 otherwise
EMPDEN =	total employment density (per acre) in the attraction zone
ATOT1M =	total employment within one mile of the attraction zone
PTOT1LM =	total employment within one mile of the production zone
HHDEN =	residential density (households per acre) in the production zone
IVTIME =	in-vehicle time (min)
OVTIME =	out-of-vehicle time (min)
WALKTIME =	walk time (min)
WAIT1 =	first wait time (for transit or carpool vehicle) (min)
WAIT2 =	second (transfer) wait time (min)
COST =	out of pocket cost ($)
WORKHH =	workers per household in production zone
MULTWORK =	1 if workers per household in production zone >1, 0 otherwise
OLDHEAD =	I if head of household is 65 or older, 0 otherwise

According to the model, increasing the travel time or cost of a mode relative to other modes would decrease the mode's probability of being chosen. Auto unavailability decreases drive alone trips and increases shared ride and transit trips. Zones with high employment densities tend to attract a higher percentage of transit trips.

Metro had begun revising its mode share model for the Western Bypass Study based on enhancements suggested in Volume 1 of the LUTRAQ study reports. The revisions included separating out-of-vehicle travel time into its components - walk, wait, and transfer time - and the initial incorporation of density variables into the model. The "original" model description here includes these changes to Metro's previously developed models.

As the utility equations show, there are already variables representing employment density in the mode choice model. For some purposes, however, the variables represent zone densities and are therefore dependent on zone size. In the revised models, these variables were replaced with ones independent of size (employment within one mile).

The other enhancement tested during the revision of the mode choice model was the inclusion of the pedestrian environment factor. While walk/bicycle trips are not modeled by the mode choice model, the pedestrian environment can have an effect on the auto/transit mode choice decision in several ways. The mode of access to transit (walk or auto) is modeled for home-based work trips, and the pedestrian environment can affect the utility of transit since a good environment can make transit more accessible. The chaining of trips can also affect mode choice; if later trips made from the destination of the modeled trip can be made more easily by walking, the tripmaker is less likely to need an automobile for these trips. In general, a better pedestrian environment increases the probability of transit use according to the revised model.

The utility functions for the revised model are as follows:

Home-based work trips:
U = 7.196 - 0.036 IVTIME - 0.06 WALKTIME - 1.081 COST - 0.109 TDIST - 1.293 VALCAR1 - 0.00003 ATOT1M for drive alone trips
U = 5.061 - 0.036 IVTIME - 0.06 WALKTIME - 1.081 COST - 0. 1 56 TDIST - 0.000037 ATOT1M - 0.031 WAIT1 + 0.459 MULTWORK for shared ride trips
U = 3,625 - 0.036 IVTIME - 0.06 WALKTIME - 1.081 COST - 0.098 TDIST + 0.552 VALCAR1 - 0.000025 TOT1M - 0.031 WAIT1 - 0.075 WAIT2 + 0.080 HHDEN + 0.088 PEF for transit trips (walk access)
U = - 0.036 IVTIME - 0.06 WALKTIME - 1.081 COST - 0.031 WAIT1 for transit trips (auto access)
Home-based other trips:
U = 3.633 - 0.033 IVTIME - 0.086 OVTIME - 0.399 COST - 0.1705 TDIST - 2.637 VALCAR1 - 1.467 VALCAR2 - 0.0000166 ATOT1M for auto trips
U = -0.033 IVTIME - 0.086 OVTIME - 0.399 COST - 2.058 WORKHH + 0.556 OLDHEAD + 0.0978 PEF for transit trips
Non-home based work trips:
U = 3.497 - 0.130 OVTIME - 0.131 TDIST - 0.0000097 PTOTlM - 0.116 PEF for auto trips
U = -0.130 OVTIME for transit trips
Non-home based other trips:
U = 4.037 - 0.127 OVTIME - 0.226 TDIST - 0.0000135 ATOTlM - 0.114 PEF for auto trips
U = -0.127 OVTIME for transit trips

where:

PEF = pedestrian environment factor (as described in the section on auto ownership) and other variables defined as in original model

Table 3 shows the comparison between the mode shares indicated by the travel survey and estimated by both the original and revised models for the trip purposes for which model revisions were performed. The comparison is shown over ranges of trip distance, employment density, and quality of pedestrian environment. Unlike the auto ownership and pre-mode choice models, the mode choice model revisions do not seem to improve substantially the capability of the model to match the survey results. This occurs for two reasons: 1) Metro had already begun incorporating density measures and making other improvements to the mode choice model based on the deficiencies identified in Volume 1, and 2) the quality of the pedestrian environment may not affect the choice between auto and transit to the extent it effects the choice of whether or not to travel by walking only. This hypothesis is being examined, in part, in a separate study being conducted by Cambridge Systematics for the Federal Highway Administration, the results of which will be available in 1993.

Table 3. Mode Choice Model Results

The first part of this table is not available at the present time.

	Survey	Original Model	Enhanced Model
Home-Based Other Trips (percent transit trips)	1.3%	1.3%	1.3%
By employment density quartiles (smallest to largest)			
1	0.3%	0.4%	0.3%
2	0.6%	0.6%	0.7%
3	1.3%	1.2%	1.1%
4	3.3%	3.3%	3.4%
By pedestrian environment levels			
<5	0.4%	0.7%	0.5%
<6	0.8%	0.8%	0.8%
<9	1.6%	1.4%	1.4%
<12	2.8%	2.7%	2.9%
Non-Home Based Work Trips (percent transit trips)	3.0%	3.0%	3.0%
By employment density quartiles (smallest to largest)			
1	0.25%	0.6%	0.8%
2	2.9%	2.0%	1.9%
3	2.2%	2.5%	2.1%
4	7.0%	7.4%	7.4%
By pedestrian environment levels			
<6	1.0%	1.9%	1.3%
<9	2.5%	2.4%	2.1%
<12	5.1%	4.7%	5.2%
Non-Home Based Other Trips (percent transit trips)	2.2%	2.2%	2.2%
By employment density quartiles (smallest to largest)			
1	0.8%	0.4%	0.8%
2	1.4%	1.4%	1.3%
3	1.2%	2.0%	1.6%
4	5.5%	5.2%	5.2%
By pedestrian environment levels			
<6	0.7%	1.0%	0.7%
<9	1.4%	1.6%	1.4%
<12	4.9%	4.4%	4.9%

Conclusions

Volume 1 of the LUTRAQ study reports identified several deficiencies in the Portland travel forecasting system that limited its usefulness in evaluating the effects of land use/transportation strategies. The consultant team, in cooperation with Metro, developed several enhancements to the models to alleviate the problems.

Four models - auto ownership, destination choice, pre-mode choice, and mode choice - were revised. Measures of development density and the quality of the pedestrian environment were incorporated into the ownership, pre-mode choice, and mode choice models, and the forms of several variables already included in the models were changed to improve their effectiveness in estimating travel demand. The method of computing intrazonal travel time was changed to improve the ability of the destination choice model to model intrazonal trips.

The model enhancements were successful in improving the ability of the forecasting system to estimate demand over wide ranges of development densities and pedestrian environmental quality. The model improvements were particularly effective in improving the ability to estimate the effects of development density and pedestrian environment on the pre-mode choice (walk/bike vs. vehicle) for home-based trips.

CHAPTER 2: LAND USE MODEL

This Chapter is not available at the present time.

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 legal action. 1000 Friends also provides staff support for the National Growth Management Leadership Project, a coalition of conservation organizations from 21 states working on growth management and land use policy. 1000 Friends is supported by its membership and tax-deductible contributions.

1000 Friends Project Staff

Keith A. Bartholomew, Project Coordinator
Mary Kyle McCurdy, Assistant Coordinator

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
Fredrick Ducca	Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.
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.

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	Bicycle Transportation Alliance
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 Khewer	Citizen Participation Organization #10, 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.
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
Jon Chandler	Home Builders Association of Metropolitan Portland
Robert Cortright	Transportation Planner, Oregon Department of Land Conservation and Development
Andy Cotugno	Planning Director, 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
Kenneth J. Ducker	Director, Center for Urban Studies, Portland State University
Barrow Emerson	Manager, Regional Rail Program, Office of Transportation, City of Portland

Brian Gregor	Senior Transportation Planner, Oregon Department of Transportation
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, 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	Director, Institute for Portland Metropolitan Studies, Portland State University
Theodore 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.

Key staff of Cambridge Systematics working on this volume are Arlee Reno, Robert Lepore and Thomas Rossi.

S.H. Putman ans Associates

S.H. Putman and Associates licenses the Integrated Transportation and Land Use Package (ITLUP), the most widely used land use model system in the United States.

Dr. Steven H. Putman, Principal of the firm, is advising Portland's Metropolitan Service District on the use of ITLUP for this project.

Parsons Brinckerhoff Quade & Douglas, Inc.

Parsons, Brinckerhoff, Quade & Douglas is the leading provider of transit planning and design services in the United States. The firm has been involved in more than 75 percent of the nation's light rail transit systems in operation or under construction today. The firm's architects have developed concepts for or designed over 200 transit stations in the last ten years.

Samuel Seskin, Lead Planner for the firm's Portland, Oregon office, is the overall Project Director for the LUTRAQ project consulting team.