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Applying an Integrated Model to the Evaluation of Travel Demand Management Policies in the Sacramento Region

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Applying an Integrated Model to the Evaluation of Travel Demand Management Policies in the Sacramento Region

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16. Abstract

The Mineta Transportation Institute at San José State University conducted this study to review the issues and implications involved in the project in question.

The primary objective of this study was to use an advanced integrated land use and transportation model to evaluate transit and supportive land use and pricing policies; the Sacramento MEPLAN model was used to simulate these policies. The model represents the effect of changes in the transportation system on land use. If the land use and transportation interaction is not represented, then the analysis of transit and highway alternatives may be biased. For example, if the land used induced travel effect is not represented in a transit alternative, then vehicle miles traveled (VMT), congestion, and emissions may be overestimated and VMT, congestion, and emissions may be underestimated in a highway alternative. Moreover, the more comprehensive representation of induced travel effects in the Sacramento MEPLAN model increases sensitivity to policies such as transit, land use measures, and pricing policies.

The major findings for this case study in the Sacramento region are:

(1) The induced travel effects of changes in land use and trip distribution may be critical to accurate evaluation of transit and highway alternatives.

(2) Integrated land use and transportation models can provide important policy in sights.

(3) Land use intensification measures accompanied by supportive transit and/or pricing policies can produce comparatively large reductions in VMT and vehicle emissions.

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EXECUTIVE SUMMARY

The objective of this study was to use an advanced integrated land use and transportation model to evaluate transit and supportive land use and pricing policies; the Sacramento MEPLAN model was used to simulate these policies. The model represents the effect of changes in the transportation system on land use. If the land use and transportation interaction is not represented, then the analysis of transit and highway alternatives may be biased. For example, if the land use induced travel effect is not represented in a transit alternative, then vehicle miles traveled (VMT), congestion, and emissions may be overestimated, and VMT, congestion, and emissions may be underestimated in the highway alternative. Moreover, the more comprehensive representation of induced travel effects in the Sacramento MEPLAN model increases sensitivity to policies such as transit, land use measures, and pricing policies.

In Chapter One, the study is introduced with background on the recent developments in the induced travel debate and the implication of induced travel with respect to regional travel demand modeling and compliance with the Clean Air Act Amendments (CAAA) and the National Environmental Policy Acts (NEPA). Recent research has provided persuasive evidence for induced travel, and the principle has been acknowledged by leading transportation researchers and by the Environmental Protection Agency. This has brought renewed attention of the inability of most regional travel demand models to represent induced travel effects; almost none represents land use and departure time choice effects, a few represent trip distribution and trip generation effects, but most represent only mode choice and trip assignment effects. With respect to the CAAA, if regional travel demand models do not account for the effect of induced travel, VMT and emissions may be underestimated in transportation plans that include highway capacity expansion. With respect to NEPA, the failure to represent induced travel effects in travel demand model simulations of new highway projects and alternatives in Environmental Impact Statements (where the objective is generally congestion reduction) would tend to overestimate the benefits of a highway project and underestimate the benefits of transit alternatives.

In Chapter Two, (Overview of the Sacramento MEPLAN Model), the theoretical framework of the MEPLAN model is described as well as the specific structure of the Sacramento MEPLAN model. The induced travel effects captured in the model are changes in land use, destination choice, mode choice, and route choice. The induced travel effects not represented are change in trip generation (number of trips) and departure time choice.

In Chapter Three, (Representation of Induced Travel in the Sacramento MEPLAN Model) sensitivity tests were conducted to evaluate the potential importance of the induced travel effects represented in the current version of the Sacramento MEPLAN model. The model was used to simulate a base case scenario (low-build) and a beltway scenario for a 25-year time horizon (from 1990 to 2015). First, the scenarios were simulated with the full Sacramento MEPLAN model set, and its implied elasticity of VMT with respect to lane miles were compared to the empirical literature. The calculated elasticity for the beltway scenario was 0.8 in 2015, which compares reasonably well to elasticities reported in the empirical literature, which range from 0.5 to 1.0 for metropolitan regions. Second, three sensitivity tests were simulated to isolate the contribution of different induced travel effects to the VMT, elasticity, and vehicle emissions results obtained from the full simulation, including land use, destination choice, mode choice, and route choice. The tests indicated that the induced travel effects most frequently represented in regional travel demand models (mode and route choice) made little contribution; however, this may be explained in part by the high occupancy vehicle lanes in the beltway network. In contrast, the tests showed that the land use and the destination choice effects, which are not typically represented in regional travel demand models, contributed significantly. This study suggests that, for this region, it may be advisable to represent the destination choice and land use induced travel effects to correctly forecast the travel and emissions impacts of significantly expanded highway capacity.

In Chapter Four, (Analysis of the Travel and Air Quality Effects of Transit and Supportive Land Use and Pricing Policies with the Sacramento MEPLAN Model) the Sacramento MEPLAN model was used to evaluate transit and supportive land use and pricing policies in the region. The policies were evaluated against travel and emissions criteria for a 25-year time horizon. Land use and transit policies were found to reduce VMT by 5% and vehicle emissions by 5% to 11% compared to a future base case scenario, and the addition of auto pricing policies increased the reductions to 10% to 17%. The use of the theoretically comprehensive MEPLAN model in this study also provided two important policy insights. First, tax and subsidy policies may not be enough to generate sufficient densities in transit-oriented developments without strict growth controls elsewhere in the region. Second, parking pricing policies in the transit-oriented developments may be a disincentive to employment location and thus may reduce their effectiveness.

In Chapter Five, (Summary and Conclusions) the results of the studies are summarized and the following conclusions are made:

- The induced travel effects of changes in land use and trip distribution may

be critical to accurate evaluation of transit and highway alternatives.

- Integrated land use and transportation models can provide important policy insights.

- Land use intensification measures accompanied by supportive transit and/or pricing policies can produce comparatively large reductions in VMT and vehicle emissions.

CHAPTER ONE

INTRODUCTION

Caroline J. Rodier

The induced travel hypothesis is grounded in economic theory and predicts that an increase in roadway supply reduces the time cost of travel and thus increases the quantity of travel demanded (or vehicle travel). The seemingly basic principle of induced travel has been the center of some debate. Recent research, however, has provided persuasive evidence for induced travel, and the principle has been acknowledged by leading transportation researchers (Transportation Research Board 1995, Transportation Research Circular 1998) and by the Environmental Protection Agency (EPA 2000).

The recent evidence for the induced demand hypothesis has brought renewed attention to the inability of most regional travel demand models to represent the effects of induced travel (Transportation Research Board 1995, Transportation Research Circular 1998). Most travel demand models account for mode and route shifts associated with induced travel, but many do not account for other induced travel effects such as changes in land use, number of trips, destination choice, and departure time choice.

The representation of induced travel effects in travel demand modeling is critical to the accurate evaluation of highway and transit alternatives. If induced travel effects are not represented in the analysis of new highway capacity, then estimates of vehicle miles traveled (VMT) and congestion will be underestimated. If these induced travel effects are not represented in the analysis of transit alternatives, then estimates of VMT and congestion will be overestimated.

The failure to represent induced travel effects has important implications with respect to the compliance with the Clear Air Act Amendments (CAAA) and the National Environmental Policy Act (NEPA).

The CAAA mandate the conformity of state air quality plans and transportation plans to meet national ambient air quality standards. Non-attainment regions use travel demand models to demonstrate that aggregate emission levels in their transportation improvement plans are not greater than the motor vehicle emissions budget in the approved state implementation plans. If regional travel demand models do not account for the effect of induced travel, VMT and emissions may be underestimated in transportation plans that include highway capacity expansions. If the requirements of the

CAAA are not met, penalties can be imposed, including the loss of federal funds for transportation projects, the imposition of stricter requirements, and possibly litigation.

NEPA requires Environmental Impact Statements for federal projects to provide information about the environmental effects of the project and alternatives to decision-makers and the public. The objective of most highway projects is congestion reduction; however, if a regional travel demand model does not account for the effects of induced travel, then congestion reduction from the highway project may be overestimated, and congestion reduction from alternatives (e.g., transit) may be underestimated. In addition, analysis of the secondary impacts of highway projects (e.g., changes in land use) is also required (Council on Environmental Quality 1987). If a regional travel demand model does not capture induced effects, then it cannot assess secondary effects.

In this study, one of the more theoretically consistent and practical integrated land use and transportation models, MEPLAN, is used to simulate the travel and air quality effects of transit and supportive land use and pricing policies. This model represents the land use and destination choice effects of induced travel in the Sacramento, California, region. In Chapter Two, we describe the Sacramento MEPLAN model. In Chapter Three, we evaluate the Sacramento MEPLAN model's representation of induced travel effects by conducting sensitivity tests of a regional beltway scenario for 25-year time horizon. In Chapter Four, we use the MEPLAN model to evaluate the travel and air quality effects of regional transit, land use, and pricing scenarios. In Chapter Five, we draw general conclusions from the results of this study.

Appendices A and B outline possible directions for work in year two of this project. In Appendix A, we describe the results of our meetings with interest groups in the region and the scenarios identified for simulation with the improved Sacramento MEPLAN model. In Appendix B, a range of potential enhancements to the Sacramento MEPLAN model are identified as well as the specific enhancements made to the Sacramento MEPLAN model as part of year one funding.

CHAPTER TWO

OVERVIEW OF THE SACRAMENTO MEPLAN MODEL

John E. Abraham

The basis of the MEPLAN modeling framework is the interaction between two parallel markets—the land market and the transportation market. This interaction is illustrated in Figure 2-1. Behavior in these two markets is a response to price signals that arise from market mechanisms. In the land markets, price and generalized cost (disutility) affect production, consumption, and location decisions by activities. In the transportation markets, money and time costs of travel affect both mode and route selection decisions.

The cornerstone of the land market model is a spatially-disaggregated social accounting matrix (SAM) (Pyatt and Thorbecke 1976) or input-output table (Leontiff 1941) that is expanded to include variable technical coefficients and uses different categories of space (e.g., different types of building and/or land). Logit models of location choice are used to allocate volumes of activities in the different sectors of the SAM to geographic zones. The attractiveness or utility of zones is based on the cost of inputs (which include transportation costs) to the producing activity, location-specific disutilities, and the costs of transporting the resulting production to consumption activities. The resulting patterns of economic interactions among activities in different zones are used to generate origin-destination matrices of different types of trips. These matrices are loaded to a multi-modal network representation that includes nested logit forms for the mode choice models and stochastic user equilibrium for the traffic assignment model (with capacity restraint). The resulting network times and costs affect transportation costs, which then affect the attractiveness of zones and the location of activities, and thus the feedback from transportation to land use is accomplished.

The framework is moved through time in steps from one time period to the next, making it "quasi-dynamic" (Meyer and Miller 1984). In a given time period, the land market model is run first, followed by the transportation market model, and then an incremental model simulates changes in the next time period. The transportation costs arising in one period are fed into the land market model in the next time period, thereby introducing lags in the location response to transport conditions. See Hunt (1994) or Hunt and Echenique (1993) for descriptions of the mathematical forms used in MEPLAN.
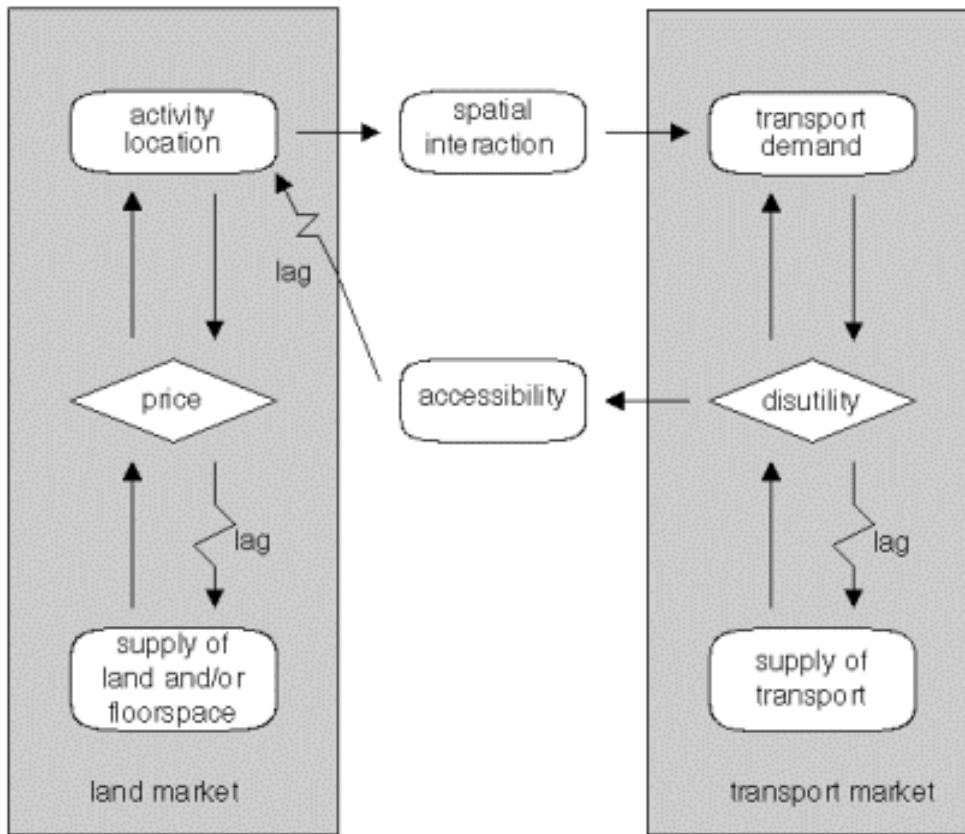
**Figure 2-1. The Interaction of the Land Use and
Transportation Markets in MEPLAN**

The specific structure of the Sacramento MEPLAN model is shown in the diagram in Figure 2-2. Table 2-1 defines the categories in the diagram. The large matrix in the middle of the diagram lists the factors in the land use submodel and describes the nature of the interaction between factors. A given row in this matrix describes the consumption needed to produce one unit of the factor, indicating which factors are consumed and whether the rate of consumption is fixed (*f*) or price elastic (*e*).

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Table 2-1. Description of Categories in Figure 2-2.

Type of Category	Category Name	Category Description
Industry and Service	AGMIN	Agriculture and Mining
	MANUF	Manufacturing
	OFSRV-RES	Services and office employment consumed by households
	OFSRV-IND	Services and office employment consumed by other industry
	RETAIL	Retail
	HEALTH	Health
	EDUCATION	Primary and secondary education
	GOVT	Government
	PRIV EDU	Private education
	TRANSPORT	Commercial transportation
	WHOLESALE	Wholesale
Households	HH LOW	Households with annual income less than $20,000
	HH MID	Households with annual income between $20,000 and $50,000
	HH HIGH	Households with annual income greater than $50,000

Table 2-1. Description of Categories in Figure 2-2. (Continued)

Type of Category	Category Name	Category Description
Land Use	ADMIN LU	Land used for agriculture
	MANUF LU	Land used for manufacturing
	OFSRV LU	Land used for services and office employment
	RETAIL LU	Land used for services and office employment
	HELTH LU	Land used for health
	EDUCATION LU	Land used for education
	GOVT LU	Land used for government
	RDES LU	Land used by residences

The Sacramento MEPLAN model uses eleven industry and service factors that are based on the SAM and aggregated to match employment and location data. Households are divided into three income categories (high, medium, and low) based on the SAM and residential location data. The consumption of households by businesses represents the purchase and supply of labor. The consumption of business activities by households represents the purchase of goods and services by consumers. Industry and households consume space at different rates and have different price elasticities, and thus there are seven land use factors in the model. Constraints are placed on the amount of manufacturing land use to represent zoning regulations that restrict the location of heavy industry. Overall development cannot exceed general plan levels. Each of these land uses (except agricultural land use) locates on developed land represented by the factor URBAN LAND. Two factors are used to keep track of the amount of vacant land available for different purposes in future time periods (MANUF VAC LAND and TOTAL VAC LAND), and the development process converts these two factors to URBAN LAND. The MONEY factor is a calibration parameter that allows differential rents to be paid by different users of the same category of land.
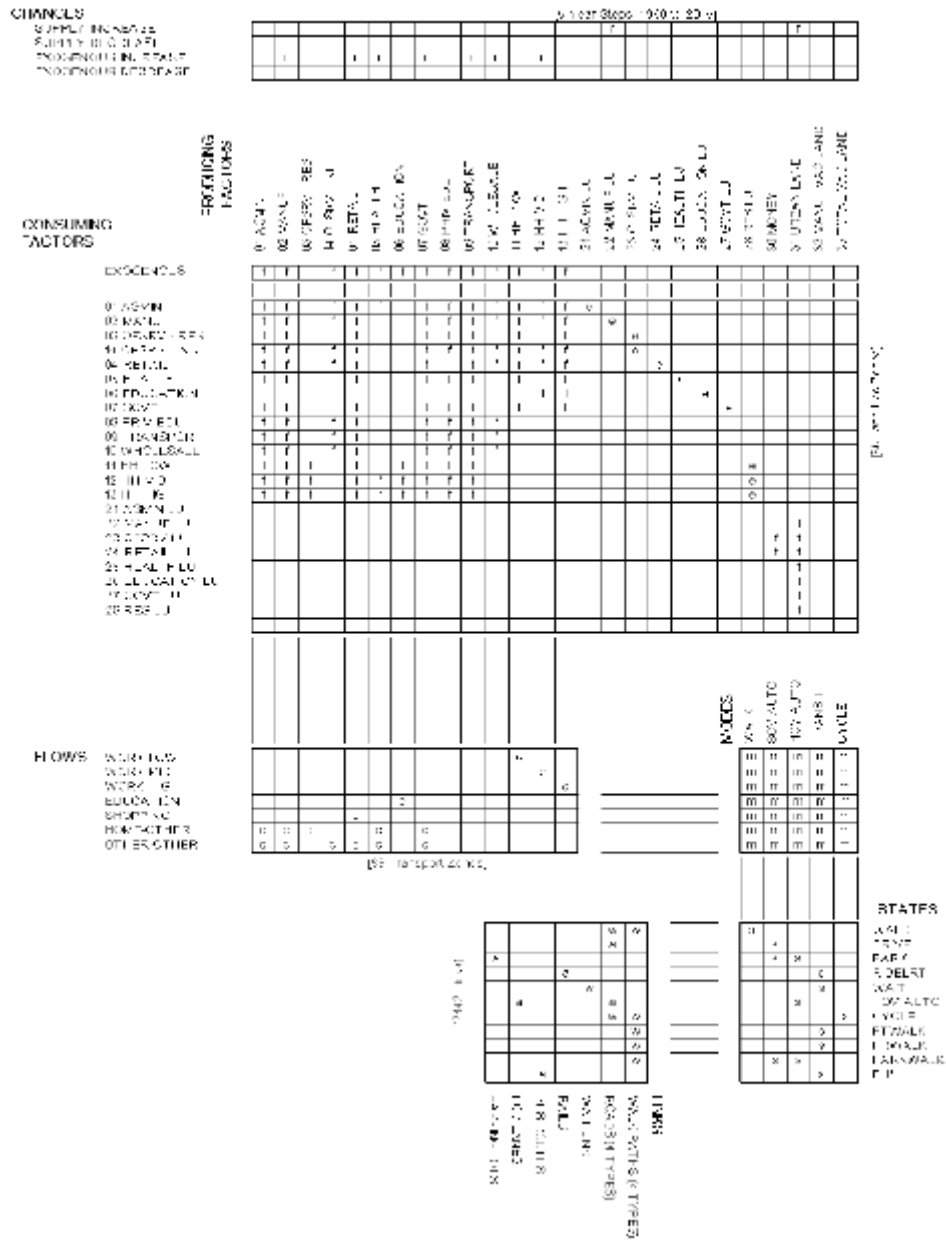
Figure 2-2. Diagram of the Sacramento MEPLAN model.

The long thin matrix just above the large matrix in Figure 2-2 shows activity that is demanded exogenously, which includes exporting industry, retired households, and unemployed households. This corresponds to the "basic" economy in the Lowry model.

The matrix directly above at the top of the diagram shows the structure of the incremental model that operates between time periods. The *r*'s for the industry and household factors indicate the economic growth in the region, and the *r*'s above the land use factors show how vacant land is converted to urban land.

The matrix on the left below the large matrix indicates the structure of the interface between the land use and transportation submodels. Each row represents one of the matrices of transportation demand and indicates the producing factors (in the corresponding columns in the matrix above) whose matrices of trades are related to that flow.

The remaining three matrices at the bottom show the structure of the transportation model. Five modes are available, and each mode can consist of several different types of activity on different types of links. The *MODES* matrix shows that all modes are available to all flows (*m*). The *STATES* matrix indicates the travel states (*s*) that make up each mode. The *LINKS* matrix shows which travel states are allowed on each transportation network link and whether capacity restraint is in effect (*a*) or not (*w*). The design of the mode choice and assignment models is based on the Sacramento Regional Travel Demand model (DKS Associates 1994). A more detailed description of the Sacramento MEPLAN model design can be found in Abraham and Hunt (1998, 1999a, 199b, and 1999c) and Abraham (2000) (see also HBAspecto.com). A discussion of the calibration of the model and the strengths and weaknesses of the model in comparison to other land use models and the Sacramento Regional Travel Demand model can be found in Hunt et al. (2001). A discussion of the strengths and weaknesses of the MEPLAN and the Sacramento Regional Travel Demand model in the context of policy analysis can be found in Rodier et al. (2001).

The parameters in the Sacramento MEPLAN model were estimated with a sequential approach in which parameters of individual submodels are estimated, and then the overall model is considered. The submodels in MEPLAN and other local models used to inform the calibration of the MEPLAN model are shown in Figure 2-3.

The local models are on the left and right side of Figure 2-3. Parameters (shown as l) were taken from the input/output economic model of Sacramento from the California Department of Water Resources and the Sacramento regional travel demand model (which uses some outside parameters in its

mode choice model) for use in the Sacramento MEPLAN model. The parameters in LUSB, TASB, and FREDA submodels were estimated separately, but the LUSA and the TASA submodels could not be estimated separately. The "spatial interaction" data at the center of the top of Figure 2-3 consists of detailed tables describing how much interaction occurs between different amounts of economic activities by type by zone. Observed data at the required level of detail were not available, and thus TASA could not be run independently of LUSA. The accessibility numbers at the center of Figure 2-3 were not available either, and thus LUSA could not be run independently of TASA. As a result, most of the parameters in both LUSA and TASA were estimated in the overall estimation process. A more detailed discussion of parameter estimation and calibration can be found in Abraham (2000) and Abraham and Hunt (1998 and 1999a).

The California Department of Transportation's (Caltrans) Direct Travel Impact Model 2 (DTIM2) and the California Air Resources Board's EMFAC7F1.1 model were used in the emissions analysis. The outputs from the travel demand model used in the emissions analysis include the results of assignment for each trip purpose by each time period (a.m. peak, p.m. peak, and off-peak). The Sacramento Area Council of Governments (SACOG) provided regional coldstart and hotstart coefficients for each hour in a 24-hour summer period.
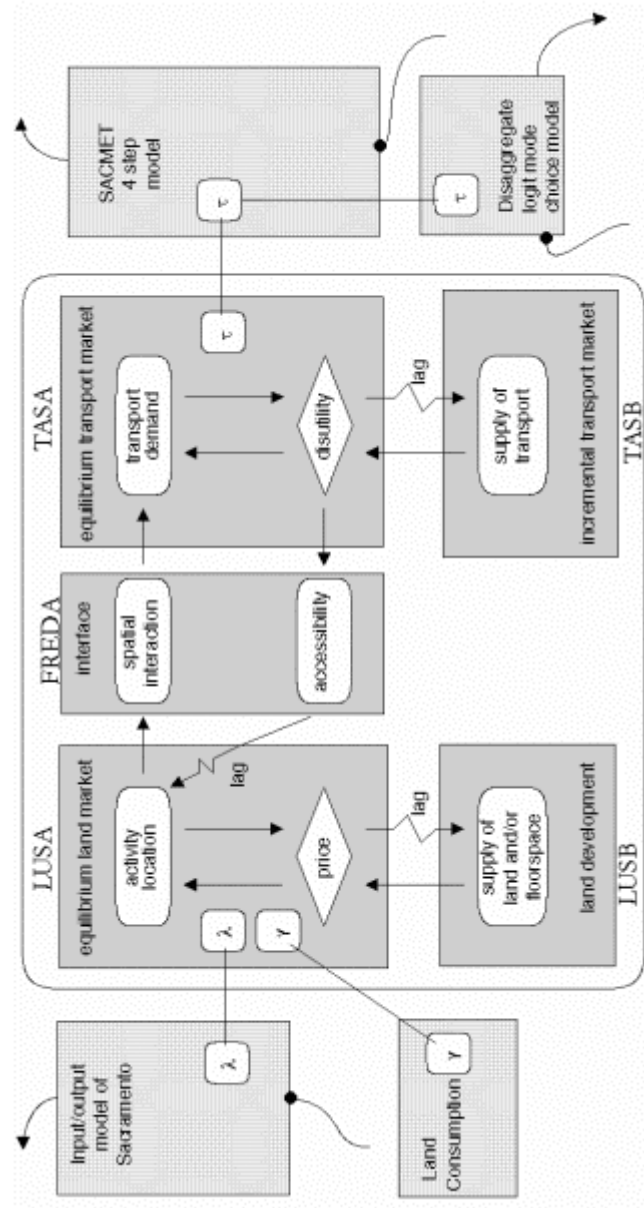
Figure 2-3. The Submodels of the Sacramento MEPLAN Model and Other Models Used to Inform Parameters.

CHAPTER THREE

REPRESENTATION OF INDUCED TRAVEL IN THE SACRAMENTO MEPLAN MODEL

Caroline J. Rodier, John E. Abraham, and Robert A. Johnston

INTRODUCTION

Recent research has provided persuasive evidence for the induced travel hypothesis, and it has been acknowledged by leading transportation researchers (Transportation Research Board 1995, Transportation Research Circular 1998) and by the Environmental Protection Agency (EPA 2000). One of the difficulties of testing the induced travel hypothesis is controlling for confounding economic activity variables such as population, income, and other demographic trends (e.g., women in the workforce). Much of the recent induced travel research has attempted to control for these variables and has not been able to reject the hypothesis of induced travel (Goodwin 1996, Hansen and Huang 1997, Noland and Cowart 2000, Chu 2000, Fulton et al. 2000, Noland 2000). The results of this research have yielded fairly consistent long-term elasticities of roadway lane miles with respect to vehicle miles traveled (VMT) (See Table 3-1). The elasticity is the percentage change in VMT divided by the percentage change in roadway land miles and the change is over time.

Table 3-1. Long-Term Elasticities of VMT with Respect to Lane Miles

Source	Geographic Region	Elasticity Range
Hansen and Huang 1997	County and Metropolitan area	0.3 to 0.7 (county) 0.5 to 0.9 (metropolitan)
Noland and Cowart 2000	Metropolitan area	0.8 to 1.0
Fulton et al. 2000	County	0.5 to 0.8
Noland 2000	State	0.7 to 1.0

Most travel demand models account for mode and route shifts associated with induced travel, but many do not account for other induced travel effects such as changes in land use, trip generation (or number of trips), trip distribution (or destination choice), and departure time choice. All of these behavioral

responses can alter a travel models' estimate of VMT. It is generally acknowledged that changes in mode choice, route choice, and departure time choice are components of induced demand; however, the importance of land use, trip generation, and destination choice effects has been a source of controversy (DeCorla-Souza, 1998).

The empirical and the modeling literature provide scant evidence on the subject (DeCorla-Souza, 1998; Dowling and Colman, 1998; Noland and Cowart, 2000). Dowling and Colman (1998) use a travel behavior survey and find that travel demand models may underpredict trips induced by a major new highway project by 3% to 5%. Coombe (1996) reviews the results of several modeling studies in the U.K. and finds that the estimates of induced travel, which include analyses of the effects of trip generation, trip distribution, mode share, and land use, in these models is not large overall. However, there is evidence that elasticities implied by transportation models calibrated against cross-sectional data in the U.K. are lower than those found in the empirical literature (Halcrow Fox and Associates, 1993). In the U.S., travel modeling studies in the Salt Lake City, Nashville, and Sacramento regions suggest that changes in trip distribution may be a significant effect of induced travel (COMSIS, 1996; Johnston and Ceerla, 1996).

In this study, an integrated land use and transportation model of the Sacramento region, based on the MEPLAN modeling framework, is used to evaluate the potential importance of land use (land development and location of population and employment) and trip distribution induced travel effects in the Sacramento, California, region. The model is used to simulate a base case scenario (low-build) and a beltway scenario for 25- and 50-year time horizons (from 1990 to 2015 and 2040). First, the scenarios are simulated with the full Sacramento MEPLAN model set, and its implied elasticities of VMT with respect to lane miles are compared to the empirical literature.

Second, three sensitivity tests are performed in an attempt to isolate the contribution of different induced travel effects. Calibrated relationships in a model may provide some guidance about the relative magnitude of separate effects of induced travel (Coombe, 1996). The scenarios are simulated holding constant the following effects from the future base case scenario to the beltway scenario: (1) the quantities of developed land in each zone, (2) land development and household and employment location, and (3) land development, household and employment location, and trip distribution. Each of these scenarios represents various methods of operating travel demand models to capture induced travel. The third scenario is equivalent to a travel demand model without feedback of assigned travel times to trip distribution;

that is, only the mode choice and traffic assignments of induced travel are represented. This is still a common method of operating travel demand models in the U.S. The second scenario is equivalent to a travel demand model with feedback to trip distribution; that is, the trip distribution induced travel effects are added to the third scenario. This scenario is analogous to a state-of-the-practice travel demand model. The first is equivalent to a travel demand model with feedback that is integrated with an activity allocation model; that is, the locations of different types of employment and population can vary with the scenario, but not quantity ("acres") of land developed. Very few travel demand analyses in the U.S. represent the land use and transportation interaction. Elasticity is calculated for each sensitivity test, and the results provide some insight into the relative contribution of land use and trip distribution effects of induced travel in the Sacramento region.

Third, the California vehicle emissions model (DTIM2 with EMFAC7F1.1 emissions factors) is used to estimate the air quality effects of induced travel in the simulated scenarios.

THE SACRAMENTO REGION

The Sacramento region is located in Northern California. In 1995, the region was estimated to have a total population of 1.8 million and total employment of about 700,000. Population is expected to grow annually at a rate of 1.9% to 2015, and employment is expected to grow annually at a rate of 2.2% to 2015 (Sacramento Area Council of Governments 1996). Average household income in 1995 was about $63,000 dollars. In the past, the employment base of the Sacramento region has been largely government and agriculture; however, more recently there has been a rapid expansion of high technology manufacturing. The residential and employment densities of the region can be characterized as medium to low. Current mode shares for home based work trips are approximately 76 percent drive alone, 17 percent carpool, 3 percent transit, 2 percent walk, and 2 percent bike.

SCENARIOS

The major transportation network improvements are made in the year 2005, and thus land use is affected in the years 2010 to 2015 (in five-year increments). See Figure 3-1 for a map of the scenario network. Regional population and employment totals are approximately the same across scenarios (i.e., the percentage change from the future base case is less than 1%) and income is consistent across scenarios.

Base Case. The base case scenario represents a financially conservative expansion of the Sacramento region's transportation system and serves as a point of comparison for the other scenarios examined in this study. This scenario would be close to the Transportation Improvement Plan for the region or the financially constrained network. This scenario includes a relatively modest number of road-widening projects, new major roads, one highway high occupancy vehicle (HOV) lane segment, and a limited extension of light rail.

Beltway. The beltway scenario adds two regional beltways (in the north, south, and east areas of the region) and an extensive expansion of the region's HOV lane system. This scenario includes 591 new lane-miles of highways, six new interchanges for the beltways, 65 lane-miles of new arterial roads to serve the beltways, and 153 lane miles of new HOV lanes. This scenario represents a 54 percent increase in new freeways and a 588 percent increase in HOV lane-miles over the base case scenario. The California Department of Transportation has studied the beltways depicted in this scenario.

Sensitivity tests of the model components that capture the induced travel effects were applied to the beltway scenario (See Table 3-2). The scenario was first simulated with the full MEPLAN model to represent all the induced travel effects captured by the model, which include land use, trip distribution, mode choice, and traffic assignment (Beltway A). Next, the scenario was simulated holding only acres of land developed constant from the future base scenario (Beltway B). Then, the scenario was simulated holding land development and population and employment location constant (Beltway C). This scenario is analogous to a regional travel demand model system with feedback of assigned travel times and costs to the trip distribution step (until the model converges). In other words, the trip distribution step is elastic with respect to changes in generalized travel costs. State-of-the-practice regional travel demand models would include these model processes. Finally, the scenario was simulated holding land development, population and employment location, and trip distribution constant (Beltway D). This scenario is analogous to a regional travel demand model system without feedback of assigned travel times and costs to the trip distribution step. Such a model would use fixed trip distribution matrices. Many regional travel demand models in the U.S. are stillcurrently operated in this manner.
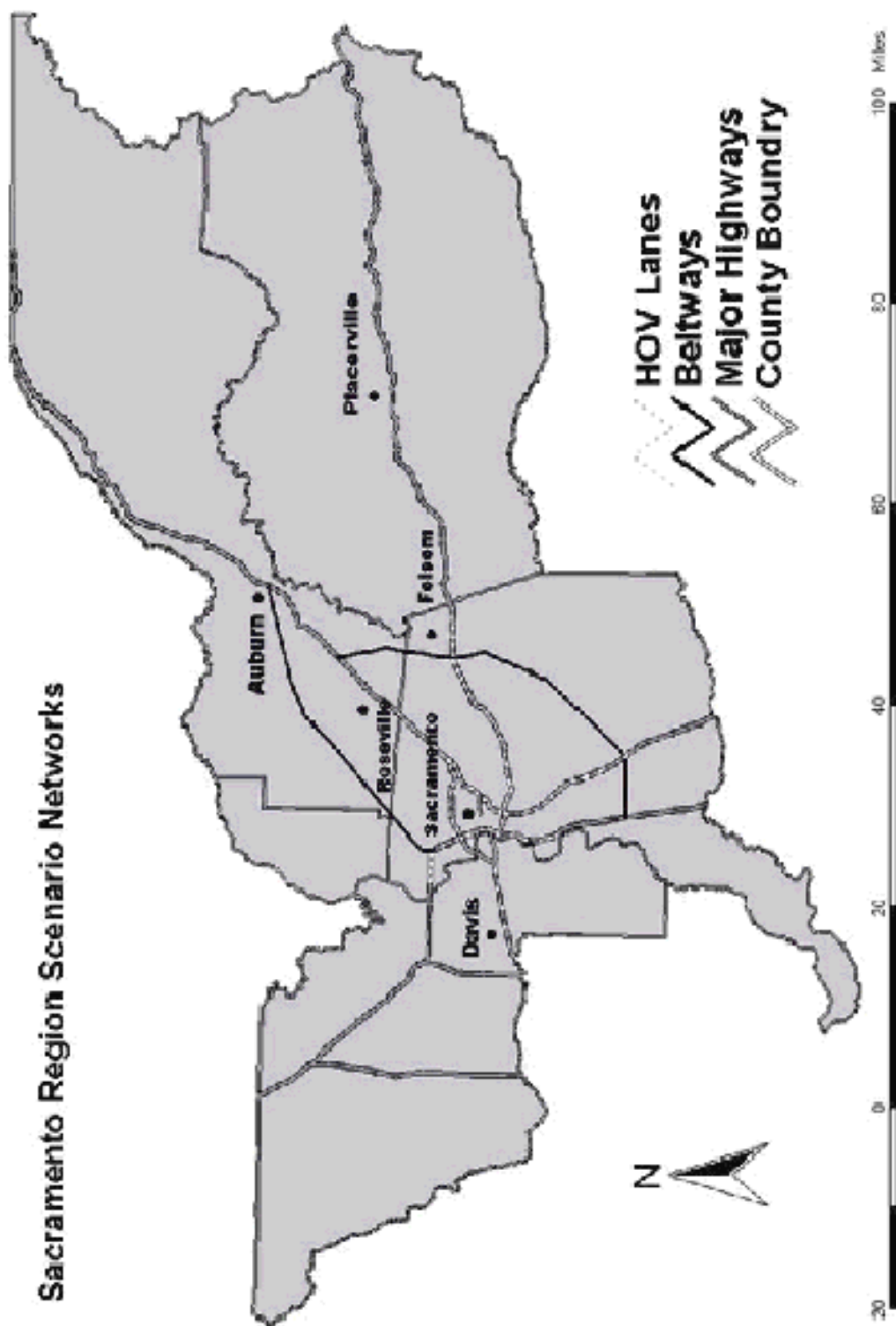
Figure 3-1. Map of the Sacramento Region Beltway Network

Table 3-2. Summary of Scenarios Simulated in the Sensitivity Analysis with the Sacramento MEPLAN model.

Induced Travel Effects	Beltway A	Beltway B	Beltway C	Beltway D
(1) Quantity (acres) of land developed	X			
(2) Population & employment location & redevelopment	X	X		
(3) Trip distribution	X	X	X	
(4) Mode Choice	X	X	X	X
(5) Traffic Assignment	X	X	X	X

RESULTS

In this section, the land use results from the full model simulation of the base case and the beltway scenarios are described, and then the travel and emissions results for the beltway sensitivity tests are compared.

Land Use

Table 3-3 presents the household and employment land use results by superzone for the year 2015 and 2040 as depicted in Figure 3-2. In the Base Case scenario, land development from 1990 to 2015 and 2040 occurs north, east, and south of the City of Sacramento. There is limited land development to the west, in Yolo County, because of exclusive agricultural zoning in the county. Over time for both the 2015 and 2040 time horizons, households and employment tend to locate primarily in existing, built-up areas northeast, east, and immediately south of the central business district (CBD). In 2040, however, households are more likely to locate in relatively more remote sections of these areas (e.g., South Sutter, Southeast Sacramento County, and El Dorado Hills). In general, household and employment location tends to follow land development; however, density increases in some zones. The land use results for the beltway scenario are discussed in comparison to the future base case scenario.

Roadway expansion in the beltway scenario encourages industry to locate further away from the households that it serves and employs. Employment location is more intense in the existing, built-up areas northeast, east, and

immediately south of the CBD, and in the CBD for both the 2015 and 2040 time horizons. Differences in employment location, however, are more dramatic in 2015 than in 2040. The opposite is true for households. In 2015 there is a movement of households further away from employment compared to the base case; however, this shift is more intense by 2040, as more households locate in the most remote eastern sections of the region.

Businesses moved around more readily than households in the Sacramento MEPLAN model in the shorter term. The constraints of existing commercial building stock are not represented explicitly in the model. That is, the model does not have a specific representation of floorspace development, and thus important differences among types of buildings cannot be distinguished and there is no representation of the cost to redevelop a building space. It is relatively easy, for example, for the model to have retail operations move into a former warehouse or an office moving into a former retail space. While the calibration of the model parameters can provide some representation of the actual "stickiness" that exists in reality, an explicit floorspace model would better simulate the difficulty of such moves by distinguishing among building types and representing the time and money needed to redevelop buildings for new use.

In the beltway scenario for both the 2015 and 2040 time horizons, the distant eastern zones that include the cities of Auburn and Folsom lose commercial employment and become more like "bedroom communities" compared to the base case scenario. As a result of increased roadway capacity, retail activity can shift from local commercial to more remote zones where "big-box" retailing is likely to occur (although the model has no direct representation of establishment size). In both scenarios and time horizons, Rancho Cordova becomes increasingly important as a commercial node east of the City of Sacramento and west of Folsom.

**Table 3-3. Percentage Change From the Base Case Scenario
to the Beltway Scenario by Superzone.**

HOUSEHOLDS	2015	2040
Sacramento CBD (13,15,50)	1%	1.6%
Citrus Heights/Roseville (70,71,4)	1%	1.7%
Rancho Cordova/Folsom (6,12)	0%	1.1%
Inner Suburbs (1-3,7-11,14,16,25)	2%	-9.2%
Outer Ring (remainder)	-1%	6.7%
EMPLOYMENT	2015	2040
Sacramento CBD (13,15,50)	4%	3.0%
Citrus Heights/Roseville (70,71,4)	1%	0.0%
Rancho Cordova/Folsom (6,12)	12%	18.2%
Inner Suburbs (1-3,7-11,14,16,25)	3%	-1.1%
Outer Ring (remainder)	-12%	-3.6%
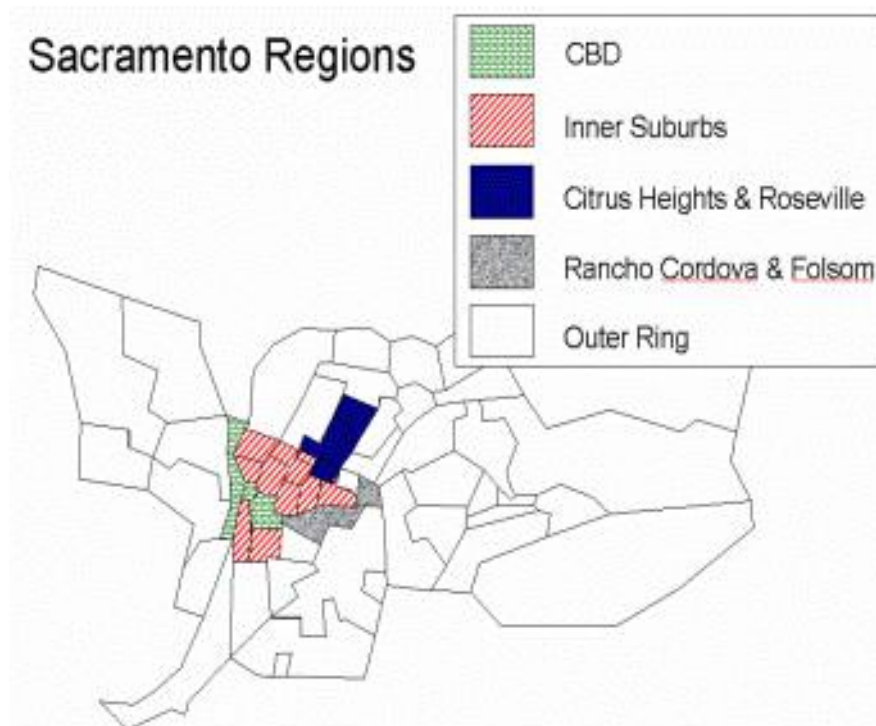
Figure 3-2. Map of the Superzones in the Sacramento Region.

Travel
The daily VMT results for the sensitivity analysis of the beltway scenario are provided in Table 3-4 and in Figure 3-3. The beltway scenario simulated with the full model (Scenario A) generates a relatively large increase in VMT compared to the base case, and this increase grows over time (13% in 2015 and 18% in 2040). Greater distances between the home and the workplace and faster auto travel speeds that result from increased roadway capacity in the beltway scenario increase VMT. The error resulting from the failure to simulate the various induced travel effects in the full model simulation (see figures in parentheses in Table 5) is, in most cases, relatively large and this error increases over time. In Scenario D, when only the mode choice and traffic assignment effects of induced travel are represented, the model predicts a small reduction in VMT because of the HOV lanes in the beltway network. In Scenario C, when the trip distribution effects of induced travel are added, the model captures approximately half of the increase in VMT found in Scenario A. Comparing Scenario C to Scenario B indicates that shifts in categories and amounts of population and employment in zones also makes a significant

contribution to induced travel in the model. Comparing Scenario B to Scenario A indicates that, when only quantities of land developed is held constant from the future base case scenario, the error is small compared to other beltway scenarios (Scenarios C to D). Thus, changes in acres developed make a relatively smaller contribution to induced travel than do changes in employment and population location

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Table 3-4. Daily VMT Results for the Sacramento Region

Scenarios: Model Component(s) Held Constant from the Future Base Case Scenario[a]	2015 percentage Change VMT
Beltway A: None (i.e., all model components are allowed to vary)	13%
Beltway B: (1) Land development	11% (-2%)[b]
Beltway C: (1) Land development (2) Population & employment location	6% (-6%)
Beltway D: (1) Land development (2) Population & employment location (3) Trip distribution	0% (-12%)

a. Base case value for 2015 VMT is 37,247,568.
b. Figures in parentheses are percentage change in VMT from the Beltway A scenario.
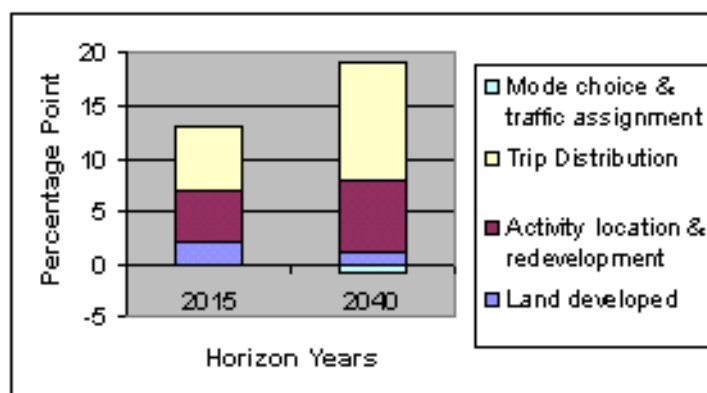
**Figure 3-3. Percentage Point Contribution of Induced Travel Effects
to Daily Change in VMT from Scenario A in 2015 and 2040.**

The results presented in the Table 3-4 and Figure 3-3 raise some issues. First, the contribution of land development and population and employment location to the total change in VMT seems to fall over time. Land use changes occur more quickly because of the absence of specific representation of different types of floorspace development (which was discussed in the previous section), and thus land use changes are probably overestimated in 2015. This result may also be specific to the sequencing of changes. The beltway freeways, which are fairly centrally located, are in place by 2005 and after that there are no more additions to the transportation network. During the 2005 to 2015 periods the beltways open up substantial quantities of previously undeveloped land. By 2040 the position of the beltways is such that they would not open up much more land for development; people would likely have already located in the area around the beltway because of population growth. By 2040 they affect travel destinations more than location and development.

Second, the contribution of land use changes to the total change in VMT seemed large to some reviewers. In the Sacramento region there are relatively large amounts of undeveloped land. This would increase the development response in this region compared to older and more built-up regions. In addition, the dominance of the automobile in the Sacramento region would tend to reduce the mode choice response compared to cities (for example, in Europe) that have a higher rate of transit ridership and cycling.

Third, it is important not to generalize the results of this study to other scenarios and other regions. The results presented will vary based on the location and timing of new highway projects in the region (e.g., congestion levels and types of geographic regions connected) and the type of new highway capacity (e.g., HOV lanes included in the network). In addition, as is the case with regional travel demand models typically the calculated results are based on a model that was calibrated on cross-sectional data and not longitudinal data that included induced travel effects.

The results of the elasticity of VMT with respect to lane miles for the sensitivity tests are presented in Table 3-5. The arc elasticity of VMT with respect to lane miles is calculated as the percentage change in VMT from the base case scenario to an alternative Beltway scenario (i.e., Scenarios A to D), divided by the percentage change in total lane miles from the base case scenario to an alternative Beltway scenario (i.e., Scenarios A to D). Note that the log arc elasticity and the mid-point arc elasticity were also calculated and the results were the same as the as the arc elasticity calculated with the formula just described. The arc elasticity is not exactly comparable to the point elasticity in the empirical literature; their comparability depends on the shape of the demand curve and the relative size of the change in the cost or supply variable.

The elasticity results for Scenario A, in which the full model was run, are similar to the empirical elasticity results from aggregate studies at the metropolitan level described above (0.8 for 2015 and 1.1 for 2040). The very long-term elasticity for the year 2040 is somewhat higher than that found in the empirical literature. Elasticity tends to increase over time as expected. The elasticity is zero when the model simulates only the mode choice and traffic assignment effects of induced demand (Scenario D). Again, this is because of the HOV lanes in the beltway network. When the trip distribution effects are added (Scenario C), approximately half of the induced travel effects are captured. Comparing Scenario C to Scenario B indicates that changes in the locations of population and employment account, approximately, for the other half of the induced travel effects. Comparing Scenario B to Scenario A indicates that the failure to represent changes in acres of land development accounts for a relatively smaller portion of the elasticity compared to the location of employment and households.

**Table 3-5. Elasticity of VMT with Respect to Lane Miles Results
for the Sacramento Region**

Scenarios: Model Component(s) Held Constant From the Future Base Case Scenario	2015 Elasticities
Beltway A: None	0.8%
Beltway B: (1) Land development	0.6% (-16%)[a]
Beltway C: (1) Land development (2) Population & employment location	0.4% (-54%)
Beltway D: (1) Land development (2) Population & employment location (3) Trip distribution	0.0% (-100%)

a. Figures in parentheses are percentage change in elasticities from the Beltway A scenario.

In the evaluation of these sensitivity tests, it is important to keep in mind a number of factors. The results will vary based on the location of new highway projects in the region (i.e., level of congestion and the types of geographic regions connected) and the type of new highway capacity (e.g., HOV lanes included in the network). Thus, the elasticity results for one scenario in the Sacramento region may not be the same for other scenarios in the region or for other scenarios in other regions. The calculated elasticities are based on a model that was calibrated on cross-sectional data and not longitudinal data that included induced travel effects. This is typical of regional travel demand models.

The similarities of the elasticity results in this behavioral model with the elasticity results from the aggregate studies (described in Table 1) increase the confidence that the results in this model and the aggregate statistical studies are reasonable. One of the critiques of the empirical induced travel studies has been that they use aggregate statistical data as opposed to disaggregate behavioral data. This study begins to address this concern because the model is more behavioral than statistical, but only certain parameters of the model were established using disaggregate data.

Vehicle Emissions

The daily vehicle emissions results are presented in Table 3-6. When the full model is used to simulate the beltway scenario (Scenario A), there is a relatively large increase in emissions. However, when the induced travel effects of only mode choice and traffic assignment are represented in the model (Scenario D), emissions decrease because of the reduction in VMT resulting from the HOV lanes in the beltway scenario. When the induced travel effects of trip distribution are added (Scenario C), emissions are largely predicted to increase, but the increase is generally less than half that obtained from Scenario A. Some pollutants are reduced in Scenario C because of increased speeds, and thus reduced vehicle hours of travel. The errors due to the failure to represent the induced travel effects of land use are relatively large in scenarios C and D. Again, when acres of land developed are held constant, the errors are comparatively smaller than errors from changes in the locations of types of employment and population. In general, emissions increase, but the error due to the failure to represent the induced travel effects is relatively stable over time.

Table 3-6. Daily Vehicle Emissions Results for the Sacramento Region

Scenarios: Model Component(s) Held Constant from the Future Base Case Scenario	2015			
	TOG	CO	NOx	PM
Base Case Values:	15.41	115.79	48.77	79.37
Beltway A: None	10%	12%	12%	8%
Beltway B: (1) Land development	7% (-3%)[a]	10% (-2%)	10% (-2%)	5% (-3%)
Beltway C: (1) Land development (2) Population & employment location	1% (-9%)	4% (-7%)	6% (-6%)	-4% (-11%)
Beltway D: (1) Land development (2) Population & employment location (3) Trip distribution	-5% (-13%)	-2% (-13%)	-1% (-12%)	-8% (-14%)

a. Figures in parentheses are percentage changes in tons of emissions from the Beltway A scenario.

CONCLUSIONS

In this study, an integrated land use and transportation model of the Sacramento region, based on the MEPLAN framework, was used to evaluate the potential importance of land use and trip distribution effects of induced travel in the Sacramento, California, region. The model was used to simulate a base case scenario (low-build) and a beltway scenario for 25- and 50-year time horizons (from 1990 to 2015 and 2040).

First, the scenarios were simulated with the full model functionality and all of the associated components of induced demand represented, including changes in land use (acres of land developed and employment and population location), trip distribution, mode choice, and traffic assignment. Very few regions in the U.S. analyze all these induced travel effects of proposed highway projects. The calculated elasticity for the beltway scenario was 0.8 in 2015 and 1.1 in 2040.

These elasticities are similar to those found in empirical work, ranging from 0.5 to 1.0 for metropolitan regions.

Second, three sensitivity tests were simulated in an attempt to isolate the contribution of different induced travel effects. The future base case and beltway scenarios were simulated holding constant the following effects from the future base case scenario to the beltway scenario: (1) quantity of developed land, (2) land development and household and employment location, and (3) land development, household and employment location, and trip distribution.

When only the mode choice and traffic assignment effects of induced travel were represented in the model (3 above), no induced travel was captured, and the elasticity was zero. In part, this was because the beltway network included HOV lanes, but it is still fair to conclude that very little induced travel was captured by changes in mode choice and traffic assignment in the model. This scenario is analogous to a regional travel demand model that uses fixed trip distribution matrices. Such travel demand models are still commonly used in the U.S.

When the trip distribution effects were added to the mode choice and traffic assignment effects of induced travel (2 above), approximately half of the induced travel effects were captured. This scenario is analogous to a regional travel demand model that includes trip distribution steps that are elastic with respect to generalized travel costs. State-of-the practice regional travel demand models in the U.S. include such processes.

When land development was held constant from the future base scenario, the results suggest that changes in acres of land developed make a relatively smaller contribution to induced travel than changes in the location of various types of employment and households. However, the two effects together account for approximately half of the induced travel. In general, we found that the contribution of land use changes became somewhat less important over time. This, however, is partially caused by the absence of a floorspace model in the current model. The model tends to somewhat overestimate the mobility of employment in shorter time horizons.

It is also felt that the lack of representation of floorspace types in the current version of the model leads to simulated employment location changes that appear to be much faster than reality. Work is currently underway to add a more dynamic and behavioral submodel of development and redevelopment. But the results reported here may have been influenced to some extent by the lack of such a submodel in the current model—in the changes in the spatial distributions of certain socioeconomic variables may have been exaggerated

and too quick.

Finally, when the full model was used to simulate the beltway scenario, it was found to significantly increase VMT (13 percent in 2015 and 18 percent in 2040) and emissions (approximately 11 percent in both time horizons). When the land use effects only were not represented and the land use and trip distribution effects were not represented, large errors were found for the estimates of VMT and emissions and, in the latter case, the rank ordering of the scenarios was altered. When origins and destinations are held constant, emissions are projected to decrease for all pollutants compared to the base case scenario because of travel time and distance saved resulting from more direct available routes to destinations (provided by the new highway capacity).

The results of the study indicate that the induced travel effects represented by the Sacramento MEPLAN model (and not typically represented by regional travel demand models) for the scenario evaluated make a relatively significant contribution to projections of VMT and emissions. The magnitude of change between the scenario and the base case is significantly altered.

Sometimes merely spatially rearranging a given amount of population and employment is discounted as a serious induced demand effect. The argument has been made that the growth would have occurred anyway but just somewhere else and so it can be ignored. The results of this study suggest that it can count for quite a bit. The effect on VMT of spatially rearranging a given level of population and employment can outweigh the effects of attracting new development that wouldn't have occurred otherwise.

Induced demand for vehicle travel occurs because people take advantage of the mobility provided by new infrastructure—people's travel and location patterns change in response to transportation infrastructure. This is a substantial mobility benefit of transportation infrastructure. This study has shown how land development models in the model MEPLAN represent, and the different mechanisms in MEPLAN contribute to induced demand, and has shown how that induced demand has costs related to the environment. Future studies should use land use and transport interaction models to establish the mobility benefits of induced demand for comparison with the environmental costs. New generations of land use and transportation models designed to enable benefit calculations may be well suited to this task.

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CHAPTER FOUR

ANALYSIS OF THE TRAVEL AND AIR QUALITY EFFECTS OF TRANSIT AND SUPPORTIVE LAND USE AND PRICING POLICIES WITH THE SACRAMENTO MEPLAN MODEL

Caroline J. Rodier, Robert A. Johnston, and John E. Abraham

INTRODUCTION

Transit, land use, and pricing policies are frequently touted as some of the most effective travel demand management measures to reduce congestion and vehicle emissions. In this study, we review the empirical and modeling literature to evaluate the effectiveness of these policies and to formulate optimal policy combinations. Next, we use the Sacramento MEPLAN model to simulate some of the most promising policies, and evaluate these policies against travel and emissions criteria.

LITERATURE REVIEW

There is a great range of findings in the literature regarding the effects of land use density and mix on auto ownership, mode choice, overall travel, and thus vehicle emissions and energy consumption. This literature review begins by presenting the conclusions of other authors' reviews and outlining some of the key debates in the literature. This is followed by our own evaluation of both the empirical and modeling literature.

In a pair of articles published in the *American Planning Association Journal*, Gordon and Richardson (1997) and Ewing (1997) review the literature on land use density on travel and come to very different conclusions. Gordon and Richardson find that the relationship between high-density development and reduced VMT and energy consumption is unclear. They cite studies by Cervero (1994) and Crane (1996) suggesting that higher density neighborhoods around transit stations will not increase transit mode shares and may even increase auto use.

However, Ewing (1997) concludes just the opposite, that is, that high-density development reduces VMT and energy consumption. Ewing asserts that Gordon and Richardson use the wrong land use variable; accessibility is significant, not density. He finds that "households living in the most accessible location spent about 40 minutes less per day traveling by vehicle than do households living in the least accessible locations" (Ewing et al. 1994, Ewing

1995). He also challenges Gordon and Richardson's use of macro-travel statistics to make conclusions about micro-travel behavior. He cites recent studies that use micro-level travel data and come to very different conclusions from Gordon and Richardson (e.g., Kitamura et al. 1995 and Ewing 1996).

A literature review is conducted by Frank (1994) and he finds two camps, those who conclude that density and mix affect travel and those who admit that density seems to affect travel, but primarily through higher parking costs and self-selection of households that prefer transit and non-motorized modes. Using the Seattle region household survey and census tract land use data, Frank finds that density and mix significantly explain the amount of vehicle travel.

A review of the empirical and modeling literatures by Breheny (1992) finds no clear evidence regarding the question of whether centralized development patterns reduce travel, emissions, energy use, and greenhouse gases. He finds only a weak preponderance of evidence that a "decentralized concentration" of medium-sized cities (which are fairly dense) have the lowest adverse environmental impacts. Several authors caution, however, that such a land use pattern could result in higher travel and energy use, unless accompanied by massive transit investments in interurban heavy rail and intra-urban light rail systems, accompanied by roads tolls and parking pricing.

A study in the U.K. examines the empirical and modeling literatures to determine the social, economic, and environmental costs of different urban patterns (Breheny et al. 1993). Its authors find that new towns with populations of 5,000-30,000 near to existing cities are weakly shown to be best on all criteria, if high-quality public transport is developed. A second U.K. study finds that, in order to minimize travel and greenhouse gas emissions, urban revitalization and medium-sized, compact new towns are necessary, again, with high levels of transit service (Ecotech Research and Consulting 1993). This study finds that many large nodes of employment throughout the urban area are environmentally superior to concentrating jobs in the central city.

An Organization for Economic Co-Operation and Development (OECD) (1995) panel of transport ministers reviewed the literature and concluded that land use policies by themselves would probably not be effective because of the low cost of travel. The transport ministers recommended urban growth boundaries, increased densities and land use mix, parking charges and limitations, roadways congestion tolls, large investments in transit, traffic calming and pedestrian streets, bike paths, and a *four-fold* increase in fuel taxes over 20 years.

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Empirical Studies

One group of empirical studies compares the mode shares and VMT of cities with different population densities. Worldwide, the auto mode share for work trips increases as the density of a city decreases. For example, in Phoenix, a city with very low population density, auto mode share is 93% and in Hong Kong, a city with very high population density, auto mode share is 3% (Kenworthy and Newman 1989). Thus, it follows that VMT is inversely related to the population density of a city.

A similar study in the U.S. used 1990 National Personal Transportation Survey data to show that VMT increases as population density decreases and that auto trips decrease as population density increases, but only at very high densities (Dunphey and Fisher 1994). The study found that a doubling of densities resulted in a 10% to 15% reduction in travel per household.

Studies of communities with different residential densities within a metropolitan region in the San Francisco Bay Area (Holtzclaw 1994), in the Puget Sound region (Frank 1994), and in the Toronto region (Nowlan and Stewart 1991) show a significant decrease in auto travel as density increases. For example, Holtzclaw (1994) finds that in several California urban regions a doubling of residential densities is associated with a 16% reduction in auto ownership rates and a 25 to 30% reduction in travel (VMT) per household. Nowlan and Steward (1991) find that for each 100 dwelling build in the central city area, about 120 inbound trips are eliminated in the morning peak period.

All of the studies that compare the mode shares and VMT of cities with different population densities are correlational and thus have difficulty controlling for confounding factors, such as demographic and transit accessibility differences between high density and low density communities.

More recent empirical studies use micro-level data (including household-level data and neighborhood-level data) in an attempt more carefully to isolate the land use effects (density and mix) on travel behavior from other causal factors. One study that did attempt to use aggregate data and control for demographic factors found a weak relationship between auto travel and population density (Schimek 1996). The results of this study are questionable because the level of aggregation used poorly represents population density.

One study examines land use on travel patterns for five different communities in the San Francisco Bay Area and uses household-level travel data. This study finds that land use variables (i.e., an increase in density, access to transit, and sidewalks) were positively related to transit and non-motorized trips and negatively related to auto travel (Kitamura et al. 1995).

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Another study in Palm Beach, Florida, that also uses household travel survey data finds that "households in a sprawling suburb generate almost two-thirds more vehicle hours of travel per person than comparable households in a traditional city" (Ewing et al. 1994).

A study in the Los Angeles metropolitan area using micro-level data, however, finds that land use variables have no significant effect on auto travel unless combined with financial incentives, but that these variables are significantly related to transit use (Cambridge Systematics Inc. and DHS 1994). The authors do acknowledge, though, that the generalizability of this study may be limited. They state that "the drive alone mode share is higher and that the development density is lower in the Los Angeles metropolitan area than in many older areas in the United States." Thus, "for these areas, the results of this study are considered a conservative estimate of the interactive effects of land use and transportation demand management strategies on mode choice."

Using 57 case studies from all over the U.S. (household-level data), Cervero finds that a mix of employment types in office areas reduce vehicle travel per worker. Residential land use nearby also reduces travel (1988). Cervero also studied households near to heavy rail and found that of the households that recently moved to the area, 29% of those who formerly drove to work now used rail transit (1994). Also, residents in those areas are about five times more likely to use transit than an average resident in the region.

National household survey data and detailed data from three large urban regions are used in a TCRP Project which found that higher density reduces auto travel for the work trip and that greater land use mix often strengthens this relationship (Parsons Brinckerhoff Quade and Douglas 1996).

Modeling Studies
A number of modeling studies that examine the effect of land use intensification around transit stations have been conducted in the U.S. Most of the studies reviewed find that these policies reduce auto travel and emissions, with two exceptions.

First, a study in the Denver area simulates a shift of all new development to transit corridors with a four-step travel model. This study finds that over 20 years roadway congestion is increased, VMT remains about the same, emissions are not generally improved, and that in the case of CO, emissions actually increase compared to the base case alternative (May and Scheuernstuhl 1991). The results of this study are limited because the travel model used could not represent the shift from the auto to the pedestrian mode, and it is not clear that the travel model is fully equilibrated on travel time and/ or cost variables. In addition, some argue that the transit corridors to which

development is shifted are far too wide.

Second, a more sophisticated modeling analysis of density policies in the Seattle region finds that the concentration of growth in several major centers reduces VMT about 4% over 30 years but that there is no clear winning scenario in terms of emissions, even including a dispersed growth scenario. It appears that the concentration of travel in the centers left the peripheral areas less congested, so people traveled farther in these areas (Watterson 1991). In this study, the travel models are equilibrated iteratively with a land use model, although the latter is less than state-of-the-art.

Other studies of density policies indicate that they are effective. Early modeling studies of the effect of high-density land uses around transit stations indicate that auto travel and energy consumption can be reduced by 16 to 20 percent (Keyes 1976, Sewell and Foster 1980).

A more recent simulation of Montgomery County, Maryland, finds that an increase in density near transit, auto pricing policies, and expanded transit may reduce single-occupant commute trips significantly (Replogle 1990). The modeling in this study is advanced because it uses land use variables in the equations for peaking factors and for mode choice.

Studies in the Sacramento region also show that density policies can be effective. One study uses a fully equilibrated travel model and shows reductions in VMT by 10 percent, fuel by 14 percent, and emissions by 8 to 14 percent over 20 years when land use intensification policies around light rail stations are combined with auto pricing policies and expanded transit (Johnston and Ceerla 1995). In another study, a similar scenario (but without pricing policies) uses an advanced travel model and finds that VMT is reduced by 4 percent and emissions by 3 to 5 percent compared to the no build scenario (Rodier and Johnston 1997).

The most recent and famous U.S. study that examines the travel and air quality effects of land use intensification policies is *Making the Land Use-Transportation-Air Quality Connection* (LUTRAQ) in Portland, Oregon. A Western Bypass highway is compared to a transit- and pedestrian-oriented development alternative. LUTRAQ finds that the land use intensification scenario reduces auto travel, congestion, emissions, and energy use considerably. It also found that:

• Auto ownership rates are 5 percent lower than in the No Build alternative.

• Fewer work trips by single occupancy vehicle than in the No Build

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alternative (58 percent compared to 76 percent for the No Build alternative).

- More than twice as many work trips by transit as the Highways Only and No build alternatives.

- Fewer vehicle trips per household each day (7.17 compared to 7.53 for the No Build alternative).

- Less peak hour traffic delay than the No Build or Highways Only alternatives.

- Fewer vehicle miles of travel than the No Build or the Highway alternatives (7.9 percent fewer than the Highways Only alternative).

- Fewer peak hour vehicle hours of travel (10.7 percent fewer than the Highways Only alternative).

- Reductions in nitrogen oxide, hydrocarbons, and carbon monoxide emissions of 2.6 to 6.7 percent compared to the No Build alternative.

- Reductions in greenhouse gas emissions and energy consumption of about 6.4 percent compared, again, to the No Build alternative. (Cambridge Systematics Inc. et al. 1996).

When auto-pricing policies are added to this alternative, the result is even greater reductions in congestion, VMT, emissions, and energy use. The transit-oriented developments (TODs) are found to contribute substantially to the results:

- About 35 percent of TOD households would choose to own only one car, and 9 percent would own none.

- Nearly 30 percent of residents would travel to work by transit.

- TOD residents would be twice as likely to walk or bike to work as residents of the study area in the Highway Only alternative.

- Children in TODs would be twice as likely to walk or bike to school as children in the study area in the Highways Only alternative.

- TOD households would need to make about 1.7 fewer car trips per day than households in the study area in the Highways Only alternative. (Cambridge Systematics Inc. et al. 1996).

The transit-oriented development policies were so successful in reducing auto travel that the Western Bypass was no longer considered necessary. LUTRAQ used an advanced regional travel demand model.

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The results of international modeling studies tend to conform to those conducted in the U.S. In one study, a set of land use and transportation models is applied to several European urban areas. The study finds that significant reductions in auto travel and emissions can only be obtained from coordinated land use planning policies when they are combined with auto pricing policies and improved transit, walk, and bike facilities (Webster, Bly, and Paulley 1988). Another simulation study, however, suggests that land use policies that concentrate populations into cities and their surrounding settlements shorten trip lengths and reduce fuel use by 10 to 15 percent over 25 years (Steadman and Barrett 1990, OECD 1995).

Conclusions

The weight of the empirical evidence suggests that land use density and land use mix can have an important effect on reducing vehicle travel and emissions. Again, however, the problem of controlling for confounding variables persists in these studies, making conclusive evidence of this relationship extremely difficult to obtain.

Modeling studies are better able to hold confounding variables constant than empirical studies, but they lack the realism of empirical studies. In addition, modeling allows tests of the effects of policies alone and in combination at larger city and regional levels. However, as we pointed out in the review, it is important to keep in mind the limitations of the model used in the study when interpreting the results. Large-scale urban models are best used as heuristic policy guides, that is, for suggesting direction and magnitude of change and rank ordering of scenarios as opposed to predicting absolute change in travel and emissions.

Despite the limitations of the empirical and modeling literature, this review suggests that land use policies alone are not effective in significantly reducing auto travel and vehicle emissions; land use policies must be supported by significant investments in transit and auto pricing policies to achieve significant reductions.

SCENARIOS

All the transportation network improvements are made in the year 2005 for the scenarios, and thus land use is affected in the years 2010 and 2015.

Base Case

The base case scenario represents a financially conservative expansion of the Sacramento regions transportation system and serves as a point of comparison for the other scenarios examined in this study. Again, this scenario is close to the Transportation Improvement Plan for the region. This scenario includes a

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relatively modest number of road-widening projects, new major roads, one freeway HOV lane segment, and a limited extension of light rail.

Pricing & Light Rail

In this scenario, approximately 75 new track miles of light rail are added to the transportation network and auto-pricing policies are also imposed. These pricing policies include a 30 percent increase in the operating cost of private vehicles (to simulate a gas tax) and a CBD parking tax representing an average surcharge of $4 for work trips and $1 for other trips. The base case scenario has almost not parking pricing. Note that this light rail network has been studied by the region and even more aggressive light rail expansions are now being considered. Figure 4-1 illustrates the light rail network.

Transit Oriented Development (TOD), Light Rail & Advanced Transit

The scenario includes the light rail network described above but not the auto pricing policies. The Sacramento MEPLAN model is theoretically comprehensive, representing land markets with endogenous prices and market clearing in each period. As a result, the model can simulate such policies as, for example, the release of zoning density caps near to rail stations, tax benefits for infill development, and land development fees on raw-land projects near the urban edge. In this simulation, increased densities in the TODs are achieved through land subsidies of 5 percent of expenditures in the year 2000 on land rent in the TOD zones. The subsidies are offset by 30 percent land rent surcharges in other zones so that region-wide the effect is revenue neutral. In other words, the cost of land rents is reduced by 5 percent in the TODs and increased by 30% outside the TODs. Note that model has only 57 zones.

In the TOD, Light Rail & Advanced Transit scenario, transit frequencies in the light rail network are doubled, and advanced transit information systems (ATIS) and local paratransit service are added. The value of wait time is reduced by a factor of three to represent ATIS, and the access time to transit in the TOD zone is reduced by 3 minutes to represent paratransit service.

Pricing, TOD, Light Rail & Advanced Transit

This scenario includes the TOD scenarios described above and the pricing policies from the Pricing & Light Rail scenario.

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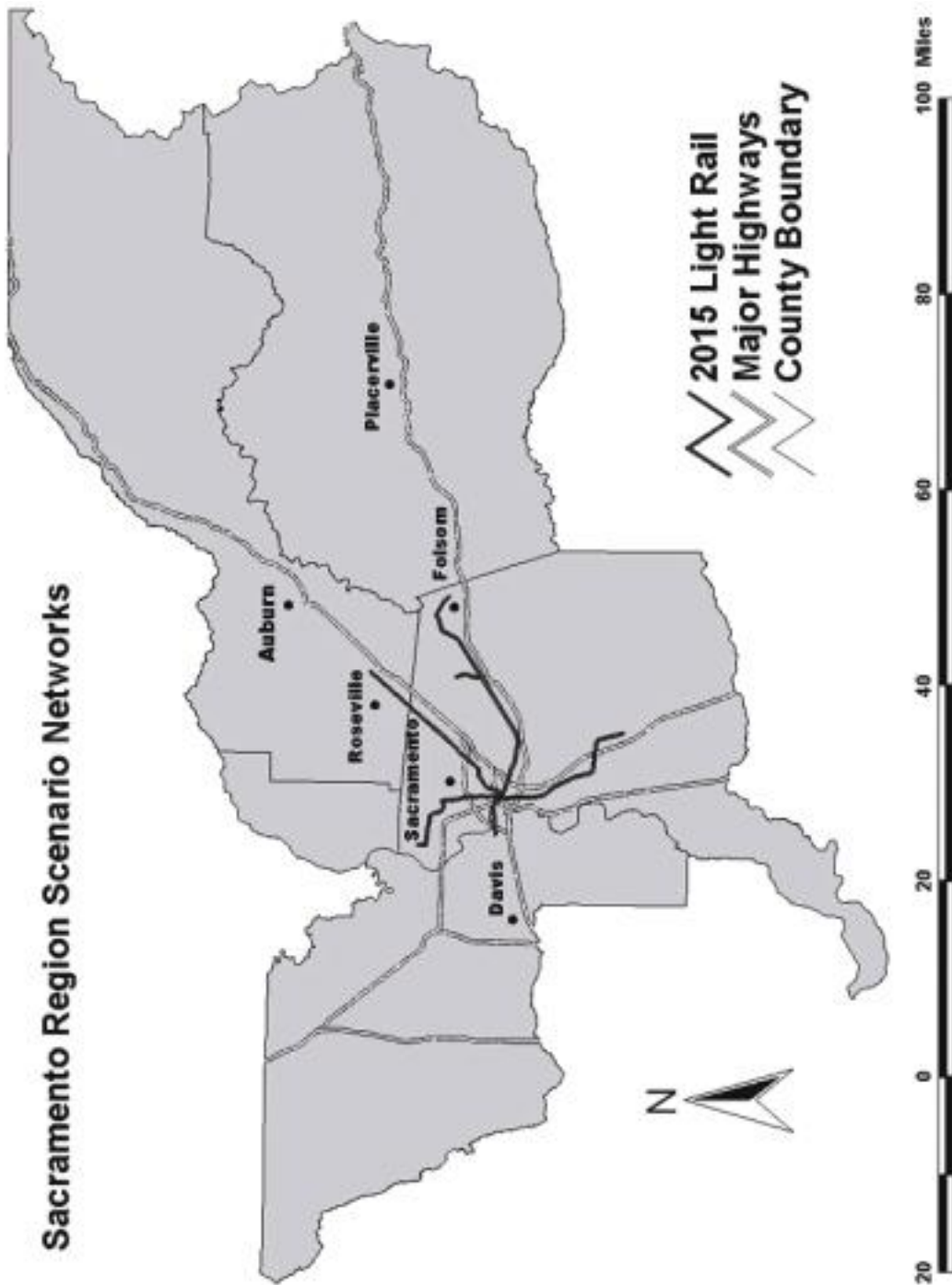
RESULTS

Land Use
In the Base Case scenario, land development from 1990 to 2015 occurs north, east, and south of the City of Sacramento. There is limited land development in Yolo County because of exclusive agricultural zoning in the county. Over time, households and employment tend to locate primarily in existing, built-up areas northeast, east, and immediately south of the CBD. In general, households and employment location tend to follow land development; however, density is increased in some zones. The land use results for the other scenarios are discussed in comparison to the Base Case scenario.

In the Pricing & Light Rail scenario, the parking charges in the CBD result in a loss of employment as businesses relocate to nearby zones to avoid the parking charges. There is also a gain in households because commercial activities are no longer willing to outbid residential activities. The increased mobility over short distances in central zones allows for a greater separation between households and employment.

The land subsidies and taxes in the TOD, Light Rail & Advanced Transit scenario have a dramatic effect on development. Almost all of the employment is attracted to zones with land subsidies, and many zones that do not have light rail service lose employment in relative terms (i.e., they have lower growth rates over time compared to the base case scenario). Households are also attracted to the subsidized zones, but to a lesser degree than employment. The rents in the subsidized zones go up, and the rents in the taxed zones go down because activities bid against each other to locate on the subsidized land. Hence, most of the subsidies and taxes ultimately flow to the landowners.

In the Pricing, TOD, Light Rail & Advanced Transit scenario, the parking pricing in many of the TOD zones offsets the benefits of subsidies in this zone and tends to dampen the migration of households and employment to the TOD zones. In general, the household and employment densities are significantly lower in this scenario compared to the TOD scenario. This suggests that parking pricing may not be compatible with TODs that are created with the use of subsidies and taxes. Strict growth controls may be needed.

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Travel and Emissions Results

In the Pricing & Light Rail scenario, there is an increase in mobility over short distances in central zones where light rail service is very good compared to the Base Case. The Sacramento MEPLAN daily mode share results for the 2015 time horizon are presented in Table 4-1. The greater separation of home and work, the availability of high quality rail service, and the increase in auto operating costs serve to increase transit mode share significantly and to reduce drive-alone mode share. There is an increase in the shared-ride mode share in this scenario (even greater than in the HOV lane scenario) because ride sharing allows the cost of travel to be shared. The walk and bike mode shares also increase. The mode shifts produce a decrease in auto trips, a significant decrease in VMT, and a slight increase in mean travel speed compared to the Base Case scenario. The Sacramento MEPLAN daily vehicle travel results for the 2015 time horizon are presented in Table 4-1.

Table 4-1. 2015 Sacramento MEPLAN Scenarios:
Percentage Changes From the Base Case

	Base (values)	Pricing & Light Rail	TOD, Light Rail, & Advanced Transit	Pricing, TOD, Light Rail, & Advanced Transit
Drive-alone share	46.8%	-6.8%	-11.6%	-11.8%
Shared-ride share	42.5%	-6.0%	-0.6%	-0.3%
Transit share	1.4%	15.0%	376.4%	374.3%
Walk & bike share	9.4%	4.7%	4.3%	4.3%
Vehicle trips	5,191,648	-2.8%	-9.1%	-9.5%
VMT	37,247,568	-6.8%	-4.8%	-10.0%
Mean travel speed	30.92 mph	0.3%	1.2%	2.2%
TOG emissions	15.41 tons	-9.2%	-8.6%	-15.4%

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**Table 4-1. 2015 Sacramento MEPLAN Scenarios:
Percentage Changes From the Base Case (Continued)**

	Base (values)	Pricing & Light Rail	TOD, Light Rail, & Advanced Transit	Pricing, TOD, Light Rail, & Advanced Transit
CO emissions	115.79 tons	-8.1%	-7.2%	-12.7%
NOx emssions	48.77 tons	-7.0%	-4.6%	-9.9%
PM emissions	79.37 tons	-0.8%	-10.9%	-16.8%

[1]Emissions analyses are conducted with the California Department of Transportation's DTIM2 emissions model and the California Air Resources Board's EMFAC7F emissions factors.

Increased densities and a better mix of households and employment in the TOD, Light Rail & Advanced Transit scenario produce dramatic increases in transit mode share and significant increases in walk and bike mode share compared to the Base Case scenario. TODs make transit use quicker and cheaper, and thus drive-alone and shared-ride mode shares are significantly reduced. Auto trips and VMT are also significantly reduced, and mean travel speed is increased slightly.

However, compared to the Pricing & Light Rail scenario, the TOD, Light Rail & Advanced Transit scenario is less effective at reducing VMT and congestion. Despite fewer auto trips in this scenario, trip lengths are longer. Thus, it appears that the pricing policies are effective at reducing trip lengths in the Pricing & Light Rail scenario.

Compared to the TOD scenario described above, the Pricing, TOD, Light Rail & Advanced Transit scenario yields only slightly greater reductions in the auto mode share, a slightly lower transit mode share, and little change in the walk and bike mode share. There is only a slightly higher reduction in auto trips compared to the TOD scenario but a larger reduction in VMT compared to the TOD scenario. Land uses are less intense in this scenario than in the TOD scenario, and thus mode share and auto trips are not dramatically changed by the pricing policy. However, the pricing policies, again, are very effective in reducing trip lengths.

In general, the Sacramento MEPLAN emissions results follow the travel results described above. The Pricing, TOD, Light Rail & Advanced Transit scenario provides the greatest decrease in emissions compared to the Base Case scenario, followed by the Pricing & Light Rail scenario, and finally the TOD, Light Rail & Advanced Transit scenario. Note, however, that the emissions reductions are relatively similar for the Pricing & Light Rail scenario and TOD, Light Rail & Advanced Transit scenario and that the PM result is lower in the TOD, Light Rail & Advanced Transit scenario than in the Pricing & Light Rail scenario. The daily emissions results for the Sacramento MEPLAN scenarios are presented in Table 4-1.

CONCLUSIONS

Land use intensification measures accompanied by supportive transit and/or pricing can produce comparatively large reductions in VMT and vehicle emissions. Land use and transit policies may reduce VMT by 5 percent and vehicle emissions by 5 percent to 11 percent, and the addition of auto pricing policies may increase the reduction to 10 to 17 percent compared to a future base case scenario for a 25-year time horizon in the Sacramento region.

The integrated land use and transportation models can provide important policy insights. The Sacramento MEPLAN model represents regional land markets, which allowed for the simulation of TOD scenarios (intensified land uses around transit stations) created by land subsidies near transit stations and land development taxes away from transit stations. It was found that tax and subsidy policies may not be enough to generate sufficient densities in TODs (i.e., density levels of prototype TODs in the region) without strict growth controls elsewhere in the region.

Because the Sacramento MEPLAN model represents the interaction between land markets and the transportation system, the model is also able to capture the effect of parking pricing policies on the location of households and employment in the region. It was found that parking pricing policies in the TODs may be a disincentive to employment location and thus may reduce their effectiveness.

The results of the analysis of the scenario in this study provided important background information for the meetings with the local interest groups in which new scenarios are identified for work in year two of this project. The results of the interest group meetings are presented in Appendix A. In Appendix B, potential enhancements to the Sacramento MEPLAN model are outlined.

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CHAPTER FIVE

SUMMARY AND CONCLUSIONS

The objective of this study was to apply an advanced integrated land use and transportation model to evaluate transit and supportive land use and pricing policies; the Sacramento MEPLAN model was used to simulate these policies. The model represents the effect of changes in the transportation system on land use. If the land use and transportation interaction is not represented, then the analysis of transit and highway alternatives may be biased. For example, if the induced travel effect of land use is not represented in a transit alternative, then VMT, congestion, and emissions may be overestimated, and in a highway alternative, VMT, congestion, and emissions may be underestimated. Moreover, the more comprehensive representation of induced travel effects in the Sacramento MEPLAN model may increase its policy sensitivity to policies such as transit, land use measures, and pricing measures.

In Chapter One, the study is introduced with background on the recent developments in the induced travel debate and the policy implications with respect to regional travel demand modeling and compliance with the CAAA and the NEPA. In Chapter Two, the theoretical framework of the MEPLAN model is described, as well as the specific structure of the Sacramento MEPLAN model. In Chapter Three, sensitivity tests are conducted to evaluate the potential significance of the induced travel effects represented in the current version of the Sacramento MEPLAN model. In Chapter Four, the Sacramento MEPLAN model is applied to evaluate transit and supportive land use and pricing policies in the region. The policies are evaluated against travel and emissions criteria for a 25-year time horizon.

A number of important findings for the Sacramento case study can be made:

The induced travel effects of changes in land use and trip distribution (or destination choice) may be critical to the accurate evaluation of transit and highway alternatives. The results of the sensitivity analysis of the beltway scenario in Chapter Three suggested that changes in land use and trip distribution contribute significantly to the VMT, vehicle emissions, and estimates of elasticity of demand for VMT with respect to lane miles. In Chapter Two, the transit and pricing scenario highlights the importance of the induced travel effect of changes in land use. In the MEPLAN simulation there is a 3 percent reduction in VMT and emissions, but the same scenario simulated by the Sacramento travel demand model (no land use effects)

showed only minor reductions (about 0.5 percent).

Integrated land use and transportation models can provide important policy insights. The Sacramento MEPLAN model represents regional land markets, which allowed for the simulation of TOD scenarios (intensified land uses around transit stations) created by land subsidies near transit stations and land development taxes away from transit stations. It was found that tax and subsidy policies might not be enough to generate sufficient densities in TODs without strict growth controls elsewhere in the region. Because the Sacramento MEPLAN model represents the interaction between land markets and the transportation system, the model is also able to capture the effect of parking pricing policies on the location of households and employment in the region. It was found that parking pricing policies in the TODs may be a disincentive to employment location and thus may reduce their effectiveness.

Land use intensification measures accompanied by supportive transit and/or pricing policies can produce comparatively large reductions in VMT and vehicle emissions. In Chapter Four, the Sacramento MEPLAN model simulations of the land use and transit policies in the year 2015 resulted in a 5 percent reduction VMT and a 5 to 11 percent reduction in vehicle emissions, compared to a future base case scenario. The addition of auto pricing policies increased the reductions to 10 to 17 percent.

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

CAAA	Clean Air Act Amendments
CBD	Central Business District
DTIM2	The California Department of Transportation's Direct Travel Impact Model 2
ECOS	An environmental umbrella group
EPA	Environmental Protection Agency
FAF	Calculated by MEPLAN's interface module FREDA
FREDA	MEPLAN's interface module
GIS	Geographic Information Systems
HOV	High Occupancy Vehicle
LUSB	Incremental Land Use Model
MEPLAN	Model to evaluate transit and supportive land use and pricing policies
NEPA	National Environmental Policy Act
SACMET	Regional Travel Demand Model
SACOG	The Sacramento Area Council of Governments
SAC-TE	An umbrella group of neighborhood and social equity groups
SAM	Social Accounting Matrix
TOD	Transit Oriented Development
TAD	Calculated by MEPLAN's transport assignment and mode split module, TASA
TASA	Transportation assignment and mode split module
TASB	Transportation assignment and mode split module
VMT	Vehicle Miles Traveled

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APPENDIX A

SCENARIOS IDENTIFIED BY INTEREST GROUPS

Caroline J. Rodier and Robert A. Johnston

We organized and attended meetings with local interest groups to identify scenarios for simulation with the Sacramento MEPLAN model. These groups include ECOS, an environmental umbrella group, and SAC-TE, an umbrella group of neighborhood and social equity groups. The region is currently undergoing a highly participatory planning process, which has been organized by the region's metropolitan planning organization (SACOG) and includes representatives from these interest groups. Members of the interest groups expressed interest in modeling scenarios that would not be addressed through this planning process. They were also very enthusiastic about the ability to simulate induced travel effects that are not captured by the region's analytical tools.

At these meetings, we presented the types of policies that can be simulated with the Sacramento MEPLAN model. We also provided them with the results (graphical and numbers) from the simulation of policies with the Sacramento MEPLAN model (reported in Chapter Four) and other studies conducted by the author's with the region's travel demand model. The following is the list of policies presented to interest group representatives:

PRICING POLICIES

The pricing policies include:

1. Parking charges applied regionally or outside transit corridors.

2. Fuel taxes or VMT taxes.

3. Peak period tolls for work trips only.

LAND USE POLICIES

Land use policies that promote increased densities and mixed-use along transit corridors could include:

1. Urban growth boundaries.

2. Conservation zones for agriculture or other environmentally sensitive lands.

3. Development subsidies near transit stations (e.g., mortgage credits or land write-downs), which could be funded with revenues from pricing policies.

4. Development taxes in outlying areas (i.e., outside transit corridors).

5. Infill development with zoning and/or perhaps subsidy and tax policies.

6. Improved pedestrian and bicycle friendliness in areas near transit stations.

TRANSIT POLICIES

The following types of transit services can be simulated:

1. Light rail and commuter rail.

2. Bus ways.

3. Express buses.

4. Conventional bus lines.

5. Paratransit.

6. Advanced transit information systems.

The representatives from the interest groups identified the following policy sets to be simulated:

1. Transit.

2. Pricing.

3. Transit and land use.

4. Transit and pricing.

5. Transit, land use, and pricing.

The groups suggested that we evaluate the new transit projects alternatives that are being examined as part of the region's ongoing planning process. They wanted to explore, in particular, some of the more aggressive transit expansion alternatives that would serve low-income neighborhoods. In addition, they asked that we explore the full range of land use policies that would support these transit alternatives. They also expressed an interest in simulating complementary parking pricing policies, in particular, parking charges outside the areas serviced by transit. The groups also were very interested in evaluating the scenarios with a benefit measure that would include the change in generalized accessibility (i.e., the time and cost of travel by all modes) from a

future base case (no-build) to a policy scenario. It was felt that this type of measure could better capture the benefits of the transit-oriented scenarios than traditional level-of-service measures used by transportation agencies.

APPENDIX B

POTENTIAL ENHANCEMENTS OF THE SACRAMENTO MEPLAN MODEL

John E. Abraham and John Douglas Hunt

INTRODUCTION

In this chapter, a range of potential enhancements of the Sacramento MEPLAN model is identified by the developers of the Sacramento MEPLAN model. Many of these enhancements would improve the model's representation of induced travel as discussed in Chapter Two. The enhancements are:

- Adding an auto ownership submodel, and making mode choice dependent on auto ownership. Auto ownership is not explicit in the current model, so there is no direct representation of how policy and transport conditions might influence the number of vehicles that people own.

- Dividing the total number of trips per day into different time periods based on travel conditions. The current model uses fixed proportions to perform this split, so the same portion of trips depart in the a.m. peak hour (for instance) regardless of policy or travel conditions.

- Adding a representation of non-trip economic interactions. Trip generation is not elastic in the current model, so the same number of trips is generated for a given amount of activity regardless of transportation conditions or policy. The rate of consumption of goods and services will remain constant in the enhanced model, but a facility will be added so that the number of trips per unit of consumption can vary depending on travel conditions.

- Changing the land and development categories and process. The representation of different land uses in the current model is done using categories that do not include density classes, and the categories are not consistent with those used in the Davis team's GIS. As well, the choices by developers are modeled using a simple model with "rule of thumb" coefficients.

- Increasing the number of zones to better model the conditions in the immediate vicinity of LRT systems.

- Adding new calculated outputs that allow a more complete comparison of scenarios.

POTENTIAL ENHANCEMENTS

Auto Ownership
<u>Design</u>

An auto ownership submodel could be added to represent people's choice of how many vehicles to own given various policy variables and conditions. This would in turn influence people's choice of travel mode.

An existing model of auto ownership in the Sacramento region is contained as a submodel within the SACMET regional travel demand model developed by DKS (DKS Associates, 1994). The SACMET submodel for auto ownership is a discrete choice model that treats four auto ownership levels (0 vehicles, 1 vehicle, 2 vehicles, 3+ vehicles) as options, with households choosing between these options. The inputs to the utilities of the four alternatives are:

- Household size;

- Workers in household;

- Household income;

- Retail employment within one mile;

- Employment within 30 minutes by transit; and

- Pedestrian environment factor index.

For the MEPLAN model, it is possible to create a similar design to the one in the SACMET model. The households would be classified two different ways. First they would be classified based on their contribution to the labor market, where income and number of workers are important, giving 12 categories, as shown in Table B-1.

**Table B-1. Segmentation of Households by Income
and Number of Workers (First Tier)**

Low	Low	Low	Low	Mid	Mid	Mid	Mid	Hi	Hi	HI	Hi
0 work	1 work	2 work	3+ work	0 work	1 work	2 work	3+) work	0 work	1 work	2 work	3+ work

These twelve categories of household would be represented as MEPLAN "factors," and would be considered the "first tier" of household categorization. They would exist in the equilibrium economic model for one of two reasons,

depending on the number of workers. The three categories of households with no employed members (0wrk) represent the unemployed and retired. They would be exogenously demanded and the incremental land use model (LUSB) would change their spatial arrangement over time in response to costs and utilities. The remaining nine categories of households with workers would be demanded by the industrial factors in the model. They would be specified as "non transportable" and assigned to their workplace location. (Because the employed households are assigned to their workplace location it will be important not to use the spatial arrangement of this "first tier" when reporting household location results.)

The "first tier" would then demand the "second tier" categorization of households. The second tier would consist of all households, divided into 48 categories by income (low, mid, high), car ownership (0, 1, 2, 3+) and number of workers (0, 1, 2, 3+). Each of the "first tier" of households would demand four of the "second tier" of households, and the rate of demand would be calculated using a logit choice function. This would represent the choice of how many vehicles to own, given household income and number of workers. The "second tier" of households would make travel choices conditional on the number of vehicles they own. Thus their transport costs would be dependent on the number of vehicles they own, and the choice of how many vehicles would depend on these costs, leading to a richer representation of how travel conditions influence vehicle choice than exists in the SACMET model.

The different numbers of workers would be a proxy for household size, and the household's need for space would also be made conditional on the number of workers. Thus the improved model would be able to predict how households of different sizes might rearrange themselves around the Sacramento region in response to changes in travel conditions and housing costs.

The design is much richer than the representation in SACMET, because it allows the number of vehicles owned to influence the spatial arrangement of activity. However it does not have the direct representation of "household size" that the SACMET model has. It may be possible to include four categories of household size as well, but that would give 48 factors in the "first tier" and 192 factors in the second tier, which may be too many factors to be manageable. Since nothing else in the model currently depends on household size little should be lost by omitting it.

Calibration
The auto ownership model will be calibrated based on a number of sources.

First, the MEPLAN design mimics the SACMET design; so the SACMET model will be considered an "extra model" (Abraham, 2000). Certain parameters and parameter relationships will be used either directly or after some manipulation. These include:

- Parameters for number of workers in household (adjusted to take into account the correlation with household size),

- Parameters for household income (adjusted to match the three income categories in MEPLAN); and

- Parameters for pedestrian environment factor in the home location.

Other parameters will be estimated in the overall calibration. Various data representing "targets" will be needed so that these overall parameters can be estimated. The targets need to be chosen so that the goodness of fit between the model and the targets is a function of the parameter value. Table B-2 shows the parameters to be estimated, the target that is sensitive to the parameter, and the data source used to find the target value.

**Table B-2. Parameters and Targets for the Estimation of
Auto Ownership Parameters**

Parameter	Target	Data Source
Dispersion parameter in auto ownership model	Arrangements of households by zones, disaggregated according to auto ownership, income, and number of workers	EHBS
Alternative specific constants		
Sensitivity to retail accessibility	Incorporated in model structure -- changes in accessibility from mode choice model affects auto ownership	N/A
sensitivity to transit accessibility		
Space consumption rates of different sized households	sq footage of housing hy household size	PUMS?

DEPARTURE TIME CHOICE

Design

The Sacramento MEPLAN model currently has a procedure to divide the all-day trips into time periods. This procedure is not sensitive to travel conditions— the same percentage of trips is loaded in the a.m. peak (for instance) regardless of congestion.

The EMME/2 travel demand model for the City of Edmonton has a peak spreading model that could be imitated for the MEPLAN model of Sacramento. This model divides the overall travel demand into 5 different time periods:

- The a.m. peak head (1 hr peak).

- The a.m. peak shoulder (2 hrs — the 3 hr a.m. peak minus the a.m. peak head).

- Off peak (represented as 12 hrs).

- The p.m. peak head (1 hr peak).

- The p.m. peak shoulder (2 hrs — the 3 hr p.m. peak minus the p.m. peak head).

The division of the total demand is done with a logit framework, with the zone-pair demand for travel being split to the various time periods according to the disutility of travel in the time periods.

The standard MEPLAN software will not be able to perform a logit split in this manner. Custom software will be written. The software will take the disutilities in the TAD file (calculated by MEPLAN's transport assignment and mode split module, TASA) and use them to split the flows in the FAF file (calculated by MEPLAN's interface module FREDA). The new program would calculate the split based on initial disutilities, call TASA once for each of the five time periods, then recalculate the splits based on the disutilities in TASA. This would be repeated until convergence.

Trip rate elasticity could be incorporated into the same program. This would add another alternative, "e-travel," to the 5 time period alternatives. The "e-travel" alternative would have a constant utility, and it would be more or less attractive, *in comparison*, as the travel attributes in the time periods change.

The "e-travel" alternative represents that economic flows generate less physical travel (and more telecommunications) when physical travel is more difficult.

The new software would be written in Java, using the MEPLAN file manipulation library from Abraham, 2000.

Calibration
The sensitivity of departure time choice to travel conditions can initially be taken from the work in Edmonton. The "time slot" constants will be estimated in overall calibration, using, as targets, the observed peaking in 1990.

The EHBS survey could also be used to inform these parameters based on Sacramento data. A cross-tabulation of trips by zone pair and time period could be used in the overall calibration, or a disaggregate model (an "extra model") could be estimated directly from the EHBS data.

LAND USE AND ALLOWABLE USE

The GIS system used by the University of California Davis (UC Davis) has different land types than the current version of the MEPLAN model of Sacramento. It is proposed to redesign the land use categorizations, based on

the GIS system. The resulting categories are shown in Table B-3 on the next page.

Table 6-3: Zoning System for the Enhanced Sacramento

MEPLAN Model

Land Zoning Designation by Planner	Space Developed by Developer						
	Vacant	Industrial	Commercial High Density	Commercial Low Density	Residential High Density	Residential Medium Density	Residential Low Density
Industrial							X
Commercial High Density							X
Commercial Low density							X
Residential High Density							
Residential Med Density							
Residential Low Density							
Urban Reserve							
Agricultural							

Shading indicates permitted uses. "X" indicates uses that are theoretically permitted, but do not appear in the base data.

In the MEPLAN implementation, each column and row of Table B-2 will be a MEPLAN factor. The development type factors (the columns in the table) will be directly consumed by activities. The factors representing land use planning designations (the rows in the table) will be consumed by the development type factors. The consumption rates will represent the type of development in each zone, and so will be unique for each zone. These consumption rates will be manipulated by custom software, written in the Java programming language using the MEPLAN file manipulation library from Abraham, 2000. This custom program will run between each time step and will model redevelopment and demolition as one process and new construction as another process.

The redevelopment and demolition model will be a logit model of the choice between 1) redeveloping into a different development type, 2) demolishing into a "vacant" type, or 3) retaining the same type.

The new construction model, also a logit model, will represent the choice of what to do with vacant land. Vacant land will include, in each time step, land previously categorized as "urban reserve" or "agricultural" but released for development as policy. The choice will be between the different types of allowable development and the choice to leave the land vacant for another time period.

In both of these submodels, the utility for each option will be a function of the average price per unit for each space development type in the zone, representing the tendency of developers to be attracted to zones and development types where existing rents are high.

- The average price per unit for each space development type in the entire region, representing that the total resources available for development are constrained and each zone has to compete with the region as a whole for development; and

- The average amount of space per employee or household compared to some reference average for the entire region, representing the tendency of developers to respond to vacancy rates.

Calibration
The data for the amount of land in each zone in each time period have been provided. The parameters of the development and redevelopment/demolition models will have to use standard "rule-of-thumb" coefficients until data on development is available.

It may be possible to do a more rigorous calibration of the development/ redevelopment/demolition models, for residential space, using the time series

data on the dwelling units by type by zone. However the submodels would not treat residential space separately from other development types, and the data (so far) are only aggregate data on the amount of development at any time, not data describing how the total is comprised of new development, redevelopment and demolition. It is probably best to seek out disaggregate data that can more directly reveal the responses of developers to prices and vacancy rates in different types of development.

The model accuracy will be substantially limited until better development data are available. If full region-wide data are impossible to acquire, then sample data should be sought.

SPATIAL DETAIL FOR LIGHT RAIL TRANSIT (LRT) ANALYSIS

The zoning system in the Sacramento MEPLAN model consists of the Regional Analysis Districts (RADs) as defined by the Sacramento Council of Governments. The zones in this system are too large to distinguish between local effects around LRT stations and broader changes.

Smaller zones could be used, but there is a lack of data on smaller zones. Smaller zones should be used across the entire region, as opposed to only around LRT stations. The reason for this is that MEPLAN's spatial allocation models are multinomial (single level) logit models of zone choice. There is no facility in the spatial allocation for using *nested* models. It is therefore important to adopt a zoning system that respects the notion that the uncertainty (error) term of the attractiveness of one zone is not correlated with the uncertainty term of the attractiveness of other zones. Each zone should be independent and should not need to be considered as a "subzone" within a "nest" of similar zones.

The micro-level nature of LRT station spatial agglomeration economies would probably be best modeled with a microsimulation model, not an aggregate model like MEPLAN. But with smaller zones there may be *some* improvement in the ability to model effects around LRT stations.

PERFORMANCE MEASURES FOR SCENARIO COMPARISON

There has been a desire to use the MEPLAN model of Sacramento to calculate "benefit measures" that can be used to compare the scenarios using the same willingness-to-pay functions implied by (or assumed in) the model's representation of decision-making. Unfortunately, MEPLAN is not designed to calculate full benefit measures.

With MEPLAN (as with most modeling frameworks), a reasonable approach is to report a number of different performance measures that, together, cover

most of what would be included in a comprehensive economic benefit measure. A list of such performance measures would be neither complete nor exclusive — some willingness-to-pay within the model may not be included in any of the measures; while other willingness-to-pay may be included in more than one measure. Nevertheless, a wide range of such computed measures can be useful in comparing scenarios.

The modeling framework, theory and use of the model would be examined to develop a number of such measures, and then the modeling system would be adjusted and enhanced to report the measures for each scenario. Table B-4 provides a categorization of possible measures; those that cannot be measured by the modeling system without substantial changes or post-processing are shown in a smaller font.

Table B-4: Possible Categorization of Performance Measures.

	Land Use	**Transport**
Economic	**Consumers (People, Firms, Shippers)**	
	Changes in Rent Changes in costs of goods, services and labor Subsidies and Taxes	Changes in accessibility (includes changes in cost of transport)
	Producers (Builders, Developers, Land-Owners, and Transport Operators)	
	Rents received Subsidies and taxes Costs of construction	Fares received Subsidies and taxes Costs of operation
	Government	
	Taxes received and subsidies given Costs of infrastructure	Taxes received and subsidies given Costs of infrastructure
Social	Distribution of land use benefits by socio economic group and area	Distribution of transport benefits by socio-economic group and area
Environmental	pressure on conservation areas open space provision pollution impact of activity	traffic noise traffic air pollution safety

Those not measurable by the current MEPLAN system without substantial post-processing are shown in a smaller font.

CONCLUSION

Funds for the year one budget allowed for the addition of the departure time choice model and improvements to the land and development process in the Sacramento MEPLAN model.

ABOUT THE AUTHORS

ROBERT A. JOHNSTON, PRINCIPAL INVESTIGATOR

Robert A. Johnston is Professor of Environmental Science and Policy and a Faculty Researcher at the Institute of Transportation Studies at the University of California at Davis. Current consulting involves the evaluation of regional travel demand models for public and private clients, reviews of environmental assessments of large projects, and the development of methods for projecting environmental carrying capacity at the national level.

Johnston's current research projects include the evaluation of transportation policies using advanced regional travel demand models. The mode choice models have been modified to permit the projection of traveler net benefits (surplus) for each scenario, broken down by household income class.

He also is performing research using an integrated urban model of the Sacramento region. This model simulates land markets and travel behavior, which permits the projection of the interactions between land uses and travel demand. This model allows the assessment of locator surplus, by household income class.

Related projects are the linking of the integrated urban model to a GIS-based model, which produced detailed land use maps. These maps are then used with other data layers to perform environmental impact assessments. Another project is a comparison of three integrated urban models on the same datasets for the Sacramento region.

Recently completed work includes financial and economic evaluations of regional transportation alternatives, including ITS roadway and transit scenarios. Current work includes performing long-range (50-year) analyses of sustainable development scenarios for the Sacramento region using an urban model and GIS, in conjunction with business and citizens groups. He is also adapting the GIS to make it interactive and run on a PC, for single-county land development scenario testing.

Professor Johnston sits on state and regional advisory committees for transportation and air quality planning agencies and has been a member of a local transportation commission. He reviews articles and grant proposals for several organizations and has published over 60 refereed articles and book chapters. He has given invited talks at many conferences and universities and has been a faculty member-in-residence at the University of Iowa. He is a member of the TRB Transportation and Land Development Committee and heads the Sustainable Communities Consortium at UC Davis.

CAROLINE J. RODIER

Caroline Rodier has a Ph.D. in Ecology, focusing on environmental policy analysis and transportation planning. As a graduate student and, more recently, as a post-graduate researcher and independent consultant, she has designed, managed, researched, and helped procure funding for a number of public research projects. The research for these projects includes the use of integrated land use and transportation, regional travel demand, and emissions models to evaluate the travel, economic, equity, and air quality effects of a wide range of transportation and land use policies. Her dissertation addresses key issues of uncertainty in travel and emissions modeling, in particular, population projections and induced travel. She has earned a variety of awards including the University of California Outstanding Transportation Student of the Year, the Federal Highway Administration's Dwight David Eisenhower Transportation Fellowship, and the Environmental Protection Agency's Science to Achieve Results Fellowship. She has authored more than 10 journal articles and 20 reports and proceedings articles.

JOHN E. ABRAHAM

John has expertise in developing and calibrating models to provide computer simulations that are both accurate and practical for analyzing policy and scenarios. His development and use of models has focused on understanding and measuring the relationship between the transportation system and the larger community, and modeling these relationships in land use transport interaction models. He is an expert on survey techniques for understanding preferences, measuring tradeoff rates and predicting behavior. Surveying projects include surveys to predict mode choice in Phoenix, Ohio, Calgary, Edmonton and Kathmandu (Nepal), and surveys to understand broad citizen preferences in Calgary and Edmonton. Modeling projects include land use and transportation models of the Sacramento region and the State of Oregon, a model of the demand for passenger traffic on the Channel Tunnel Rail Link, a model of cyclist's preferences of Edmonton, a mode choice model for Kathmandu, Nepal, and a review of the land use model of Auckland, New Zealand. As a volunteer, John has worked with stakeholder groups and community associations, and is chair of the Calgary Alternative Transportation Co-operative. John is also president of T.J. Modelling Ltd.

JOHN DOUGLAS HUNT

Doug is an internationally recognized and widely published expert in land use and transport interaction modeling. He has about 15 years of experience in transportation demand modeling and land use transport interaction modeling in

Europe, the United States, and Canada. He has assisted in the successful development of multimodal transportation models or land use and transportation interaction models for various cities, including: London, Edinburgh, Dortmund, Naples, Dublin, San Diego, Sacramento, Phoenix, Edmonton and Calgary. He was a special modeling advisor to Union Railways, the British Rail subsidiary developing the Channel Tunnel Rail Link, for 4 years. He has also worked on regional transportation and land use model for Oregon, Sweden, Southeast England and Central Chile. His special expertise is in the design and calibration of these models, developing them so that they can be used to examine policy alternatives involving such things as infrastructure development, alterations in land use regulations, changes in transportation conditions (including operations, tariffs and user costs) and new economic and fiscal arrangements. His experience in both private consulting and university teaching and research make him a powerful communicator with a broad understanding of both the technical issues and the practical constraints involved in real-world modeling work. Doug is a professor of Transportation Engineering at the University of Calgary and president of Hunt Analytics Incorporated.