Title

Verifying the Accuracy of Land Use Models Used in Transportation and Air Quality: A Case Study in the Sacramento, California Region

Author

Rodier, Caroline J.

Publication Date

2005-08-01

Year 2005

UCD—ITS—RR—05—16

Verifying the Accuracy of Land Use Models Used in Transportation and Air Quality Planning: A Case Study in the Sacramento, California Region

Caroline J. Rodier, Ph.D.

Institute of Transportation Studies ◇ University of California, Davis
One Shields Avenue ◇ Davis, California 95616
PHONE: (530) 752-6548 ◇ FAX: (530) 752-6572
WEB: http://its.ucdavis.edu/

VERIFYING THE ACCURACY OF LAND USE MODELS USED IN TRANSPORTATION AND AIR QUALITY PLANNING: A CASE STUDY IN THE SACRAMENTO, CALIFORNIA REGION

Caroline J. Rodier, Ph.D.
Research Associate, Mineta Transportation Institute
Assistant Research Engineer, California PATH
1357 S. 46th Street. Bldg 190; Richmond, CA 94804-4648
510-665-3467 (O); 916-451-8188 (F); cjrodier@path.berkeley.edu

Submitted to Transportation Research Board (TRB)

July 2005

Word Count: 7,342

ABSTRACT

To help guide applications of more advanced models in policy studies, this paper presents an evaluation of model accuracy and induced demand in an integrated land use and transportation model, the 2000 Sacramento MEPLAN model. The model is currently used by the region's metropolitan planning organization (MPO) for land use projections. The accuracy of the model is assessed with validation tests that show how well the model predicts observed data over a ten-year period that are not used to estimate or calibrate the model. Forecasts are compared to observed 2000 land use and travel data to identify the magnitude of model error resulting from model functional forms and parameter specifications. Forecasts are also used to identify the model's representation of induced demand and to estimate actual induced demand. The model's representation of induced demand includes the change in land use (i.e., development and allocation) and travel (trips, distance, mode choice, and time) that results from new transportation capacity. The results illustrate how validation tests can be used to improve the application of uncertain models in policy studies requiring absolute accuracy such as conformity analysis (emissions budgets) and environmental impact analysis (level of roadway service).

Key Words: Land use models; Transportation planning; Travel demand; Travel demand management; Trip distribution; Induced demand

INTRODUCTION

Driven by regulatory and legislative mandates, state and regional governments across the U.S. are beginning to implement more advanced land use models to evaluate transportation and air quality plans. The 1990 Clean Air Act Amendments' conformity regulations require a logical correspondence between future regional land use projections and transportation plans in serious or worse non-attainment regions[1]. A U.S. District Court case in the Chicago region held that the National Environmental Policy Act requires the consideration of land development changes when a new freeway segment is analyzed. The 1998 Transportation Equity Act for the 21st Century urges the consideration of the effects of transportation policy decisions on land use and economic development. Increasingly, peer reviews of travel demand models recommend that regional planning agencies represent the effect of their transportation plans on land uses projections (e.g., in Salt Lake City, Utah, (*1*) and Atlanta, Georgia (*2*)). Citizens are also asking public officials what effect new beltway freeways and major transit projects will have on land development, household and employment location, and the local economy.

On the other hand, the requirements and demands for more advanced modeling of land use and transportation systems also raise valid questions about the accuracy of their projections and thus their appropriate application in policy studies. Theoretical improvements in models may reduce projection error; however, their implementation tends to require more complex model structures, which may increase other sources of error, such as calibration, measurement, and specification. It is possible that the error reduction due to theoretical improvements may be offset by other sources of errors associated with more complex modeling systems.

To help guide applications of these more advanced models in policy studies, this paper presents an evaluation of model accuracy and induced demand in the 2000 Sacramento MEPLAN model, an integrated land use and transportation model. The model is currently used by the region's metropolitan planning organization (MPO) for land use projections and they are currently in the process of implementing a more advanced integrated model called PECAS (*3*). The accuracy of the model is assessed with validation tests that show how well the model predicts observed data over a ten-year period that are not used to estimate or calibrate the model. Forecasts are compared to observed 2000 land use and travel data to identify the magnitude of model error resulting from model functional forms and parameter specifications. Forecasts are also used to identify the model's representation of induced demand and to estimate actual induced demand. The model's representation of induced demand includes the change in land use (i.e., development and allocation) and travel (trips, distance, mode choice, and time) that results from new transportation capacity. The results illustrate how validation tests can be used to improve the application of uncertain models in policy studies requiring absolute accuracy such as conformity analysis (emissions budgets) and environmental impact analysis (level of roadway service). This study begins with a literature review on model error, next the methods used in the study are described, then the results of the evaluation are presented, and finally conclusions for the case study are made.

LITERATURE REVIEW

A few studies address the potential benefits of a theoretically improved model set that represents the land use and transportation interaction. Condor and Lawton (*4*) compare the results of travel demand model simulations for a future transportation plan that uses fixed land use projections and modeled land use projections and show that congestion and the long-term need for

---

[1] 40 CFR 93.122[b][1][iii]

transportation investment are overstated when the land use model is not linked to the travel demand model. Rodier (*5*) isolates the contribution of the land use and transportation interaction to travel and vehicle emissions analyses over 25- and 50-year time horizons in the first version of the Sacramento MPELAN model and finds that land use change induced by highway expansion accounts for approximately 50 percent of the induced travel. Marshall and Grady (*6*) conduct a sensitivity analysis of the Chittenden County (Burlington, Vermont) MPO's land allocation and travel demand model set and find that the scenario comparison show change in land uses has little effect on travel because, under conditions of rapid population growth and minimal roadway investment, "the land use allocation model may be acting as a brake on land use decentralization in both the No-Build and the Build cases" (*6*).

Two recent studies evaluate the effect of input data and parameters error in land use models on their forecasts. Pradhan and Kockelman (*7*) apply Monte Carlo methods to the UrbanSim model and find that "while several model inputs may affect model outputs in the short run (mobility rates), only those inputs that have a cumulative effect are likely to have a significant impact on outputs in the long run (aggregate growth rates)" (*7*). Rodier (*8*) conducts a sensitivity analysis with plausible errors in total population, fuel price, and income projections using an earlier version of the Sacramento MEPLAN model and finds that these errors are more significant in projections of land development than travel.

Sensitivity tests of potential errors in model inputs and parameters suggest specific sources of model errors, but only whole model validation can demonstrate how well a model (functional forms and parameters) predicts actual observed behavior. The author is aware of only one validation study of a land use model. Waddell (*9*) conducts a historical validation of the Eugene/Springfield (Oregon) UrbanSim model using an R-square measure of goodness-of-fit between the 1994 predicted versus observed employment, population, land value, and development square feet. As the level of aggregation increases, so does the goodness-of-fit (results for cells ranged from 0.45 to 0.64 and from 0.64 to 0.88 for zones). Rodier also conducts an historical validation study of the 1991 Sacramento regional travel demand model (*8*) over a nine-year period and finds that the model overestimates vehicle miles traveled, vehicle hours traveled, and vehicle hours of delay (5.7 percent, 4.2 percent, and 17.1 percent, respectively), that errors in land use projections approximately double these errors, and that the model underestimates induced travel.

METHODS

The Sacramento MEPLAN Model

The MEPLAN modeling framework belongs to the family of integrated transportation-land use models that combines spatial input-output representation of the land market with random utility models of location choice. The framework has been applied around the world for over 20 years and is readily available for calibration; however, the Sacramento MEPLAN model is the first application in the U.S. The Sacramento MEPLAN model (version 3e) represents the regional economy and land market, redevelopment, as well as the effect of travel time and cost on the location of activities and travel decisions such as destination, mode, and route choice. The model was originally calibrated to the year 1990 at the University of California, Davis, as part of an urban modeling comparison project. The Mineta Transportation Institute funded key improvements to the model, and now the model has been adopted by the Sacramento Area Council of Governments (SACOG). SACOG invested significant resources in the current version of the model to recalibrate it to the year 2000 with improved model data, to include Sutter and Yuba counties, and to represent more detailed transportation networks. This present version uses 71 regional analysis zones. The developer model was calibrated to keep weighted average floorspace prices stable across the region in a long-term simulation and to provide an appropriate response to “price shocks” exogenously specified (i.e., sudden increases in rents). The price shock response was based on expert opinion and overall system stability. The stability criterion was based on the earlier version of the model with five year time steps; the current model, with two-and-a-half-year time steps, could accommodate greater price response in the developer model. Detailed documentation of the Sacramento MEPLAN model can be found in the Mineta Transportation Institute Report 01-819 (*10*) as well as numerous published papers (*11,12,13,14, 15*).

Validation Tests

In the process of developing a travel demand model, the model is estimated on local data, and then calibrated or adjusted to closely match observed data. However, the observed data are the same data used to develop and calibrate the model. Thus, calibration results are a very limited measure of model accuracy. Validation tests show how well the model predicts observed data that are not used to estimate or calibrate the model. In this study, the 2000 Sacramento MEPLAN Model (version 3e) is used with observed data to test model accuracy and representation of induced demand over a ten-year period.

Tests of Model Accuracy

Land use and travel for the year 2000 is simulated with the Sacramento MEPLAN model (calibrated to 2000 data) with the year 1990 observed household, employment, vacant land, and land developed by zone; observed regional employment and population growth from 1990 to 2000; and observed transportation networks for each model time step from 1990 to 2000. This simulation is called Forecast 2000 in Table 1. The land use and travel results from Forecast 2000 are compared to available observed 2000 data to assess model error.

Errors in forecasts are represented by both algebraic and absolute errors. The algebraic error (*ALE*) is calculated as:

$$ALE_i = F^1{}_i - O^1{}_i \tag{1}$$

where F^1 is the Forecast 2000 value, O^1 is the observed 2000 value, and *i* is a Sacramento MEPLAN zone for land use categories or regional travel category (e.g., total regional mode share, distance, or time). The mean algebraic error (*MALE*), where *n* is equal to the total number of zones, is calculated as:

$$MALE = \frac{\sum ALE_i}{n} \tag{2}$$

Next, the algebraic percent error (*ALPE*) is calculated as:

$$APLE_i = \left(\frac{ALE_i}{O_i^1}\right) * 100 \tag{3}$$

Finally, the mean algebraic percent error (*MALPE*) of the forecasted value across zones is calculated:

$$MALPE = \frac{\sum ALPE_i}{n} \tag{4}$$

The absolute value of the $ALPE_i$ ($|ALPE_i|$) is the absolute percent error (APE_i).

Tests of Induced Demand

The land use and travel changes induced by the expansion of the regional transportation network from 1990 to 2000 are estimated by simulating the year 2000 holding the 1990 network constant for each future time step (1992 to 2000). This forecast is called Forecast 2000 with 1990 network in Table 1. Thus, the only difference between this simulation and the Forcast 2000 simulation used in the model accuracy test is that the year 1990 roadway and transit network does not changes throughout the simulated time steps to the year 2000. The major roadway networks expansion from 1990 to 2000 include new HOV lanes along state route 99 from downtown Sacramento to Elk Grove; two new interchanges on I-5 at Laguna and Elk Grove Boulevard in South Sacramento; new or improved highway interchanges on I-80 west of Sacramento in Davis; and new or expanded major arterials in the East Sacramento, Folsom, Natomas, Roseville, and Rocklin areas (see Figure 1 for city and highway locations). In total, these roadway expansion projects represent a 3.8 percent change in total regional lane miles from 1990 to 2000. Light rail was also expanded east of Sacramento from downtown during this time period.

The Sacramento MEPLAN model's representation of induced demand is evaluated by comparing forecasted values from the year 2000 simulation with the 1990 network to the year 2000 simulation (Forecast 2000) and observed 2000 data. The difference between the two forecasts is defined as the *model* algebraic change (*MALC*), which is calculated as:

$$MALC_i = F^1{}_i - F^2{}_i \tag{5}$$

where F^1 is the Forecast 2000 value, F^2 is the Forecast 2000 with the 1990 network value, and i is a Sacramento MEPLAN zone for land use category or regional travel category (e.g., total regional mode share, distance, or time). Next, the magnitude of separation between forecasts as represented by a percent difference is defined as the *model* algebraic percent change (*MALPC*), which is calculated as:

$$MALPC_i = \left(\frac{MALC_i}{F_i^2} \right) * 100 \tag{6}$$

The *MALPC* represents the degree to which the forecast with a variant network (Forecast 2000) is different from the forecast with a constant network (Forecast 2000 with 1990 network) as a percentage of the constant network forecast. The absolute value of the $MALPC_i$ ($/MALPC_i/$) is the model absolute percent change ($MAPC_i$).

In addition, the results of Forecast 2000 with the 1990 network are compared to observed 2000 data to estimate actual induced demand over the 10-year period. This is the estimate of induced demand corrected for model error as identified in the previous section. It is important to note that the correction is approximate because a simulation keeping the 1990 network constant may increase or reduce the error in the simulation results; however, because the network change is relatively small, such biases may be relatively small.

The *estimated* algebraic change (*EALC*) is calculated for land use types by zone or total regional travel value:

$$\mathrm{EALC}_i = \mathrm{O}^1_i - (\mathrm{F}^2_i(1- \mathrm{ALPE}_i)) \qquad (7)$$

where O^1 is the observed 2000 data value, F^2 is the Forecast 2000 with the 1990 network value, ALPE is the algebraic percent error, and *i* is a Sacramento MEPLAN zone for land use category or regional travel category. Next, the *estimated* algebraic percentage change (EALPC) is calculated as:

$$EALPC_i = \left[\frac{EALC_i}{F_i^2\left(1 - APLE_i\right)}\right] * 100 \qquad (8)$$

The $EALPC_i$ is the difference between the observed data value and the error adjusted constant network forecast, as a percentage of the error adjusted constant network forecast. If the error adjusted constant network forecast overestimates the actual travel demand, then the $EALPC_i$ will be negative. If it underestimates travel demand then the $EALPC_i$ is positive. The absolute value of the $EALPC_i$ ($|EALPC_i|$) is used to calculate the estimated absolute percentage change ($EAPC_i$).

TABLE 1 Description of forecasts used in validation tests

Forecasts	Network	Input Land Use
Model Accuracy Forecast 1 (F^1) "Forecast 2000"	1990 1992 1995 1997 2000 +3.8% road lane miles	1990 observed households, employment, vacant land, and developed land by zone
		1990-2000 observed regional population and employment growth
Induced Demand Forecast 2 (F^2) "Forecast 2000 with 1990 network"	1990 (for all time steps)	1990 observed households, employment, vacant land, and developed land by zone
		1990-2000 observed regional population and employment growth

Observed Data

The socioeconomic data used in the simulation studies were developed by SACOG with annual housing and tri-annual employment inventories, housing inventories, census data, and population estimates from the California State Department of Finance Demographic Research Unit. Land use data (households, employment, vacant land, and acres of developed land by zone) were also developed by SACOG. Parcel-level data were collected to inventory vacant and developed land.

The observed travel results were obtained from the Sacramento MEPLAN Model (version 3e) calibrated to 2000 data. The best estimates of comparable person miles of travel, average travel time, and speed for the morning peak hours were only available from the Sacramento MEPLAN model. In general, this type of data is often not available because of limited sample size. Observed vehicle ground counts were not available for the year 2000 and thus could not be used in this study.

The 2000 socioeconomic, land use, and travel data used in this study were the best available data of observed conditions for the region. These data are estimates, rather than counts, and thus there is potential for measurement error. In addition, it is also possible that zoning restrictions in the model, as represented in the zonal land inventory, may contain some errors. It is not possible to quantify the magnitude or direction of these potential errors. However, any error in the observed data and policy inputs in this study would affect the accuracy of error evaluations and the conclusions of this study.

RESULTS

Test of Model Error

In this section, the results of the test of model error in which results the land use and travel results from the year 2000 forecast, simulated with the model calibrated to 2000 data with the year 1990 observed input data, is compared to available observed 2000 data.

The distribution of zones with ± 10 to 100 percentage points of their mean algebraic percent error are depicted in Table 2. These results indicate that approximately 72 to 85 percent of the zones across the land use categories within ±100 percentage points. More zones have lower algebraic errors for the employment and non-residential land forecasts (56 and 34 percent, respectively, within ±50 percentage points) relative to the household and residential land forecasts (14 and 18 percent, respectively, within ±50 percentage points).

The distribution of the algebraic percent errors are positively biased across all land categories with means ranging from seven to 86 percent. However, the algebraic errors are negatively biased for employment and household forecasts with means of -240 and -190, respectively and positively biased for non-residential and residential acres with means of 30 and 62, respectively. The global production changes to exogenous production estimated with observed data appear to underestimate total regional households and employment by almost two percent and overestimate total regional residential and non-residential land development by 25 and 15 percent, respectively. In general, zones with relatively small initial values are just as likely as zones with relatively large initial values to have high algebraic percent errors.

TABLE 2 Percent of zones with mean algebraic percent error + 10 to 100 percentage points by land category

Percentage points	**Employment (7%[1] & -240[2])**	**Non-Residential Acres (54% & 30)**	**Households (60% & -190)**	**Residential Acres (86% & 62)**
±10%	11%	7%	1%	1%
±20%	20%	10%	1%	6%
±30%	34%	21%	8%	10%
±40%	48%	30%	10%	11%
±50%	56%	34%	14%	18%
±60%	66%	45%	24%	25%
±70%	73%	51%	35%	28%
±80%	79%	61%	58%	37%
±90%	82%	65%	72%	62%
±100%	85%	72%	76%	72%

[1] MALPE or mean algebraic percent error.
[2] MALE or mean algebraic error.

Algebraic percent errors for employment and households are depicted in Figures 1 and 2, respectively. Because of the underestimation of total population, most zones in the region (48 of the 71 zones for employment and 42 zones for households) have relatively modest, negative algebraic percent errors (between -100 to zero percent). There are relatively modest errors (between one and 50 percent) for the more established central urban areas of Sacramento County, Rancho Cordova, and Roseville. In general, however, the model appears to overestimate the location of households and employment in the outer areas of the region with relatively less expensive land. These errors may be explained by two factors. First, the developer model lacks sensitivity to prices because of limited price data and/or parameter calibration. Second, the large zones with only one centroid connector in the outer regions may underestimate travel times to those zones. These results suggest a need to calibrate the model to two different points in time (e.g., two, five, or ten years apart) to improve the model's representation of land use trends over time.

The same data used in this validation study could be used to improve model calibration over time. The accuracy of the land forecasts are evaluated by examining the share of the total number of zones less than or equal to the absolute percent error. Eighty percent of the zones have absolute percent errors for employment and households within zero to 75 percent and for non-residential and residential land within zero to about 110 percent. Thirty percent of zones for employment and non-residential land and 50 percent of zones for households and residential land have absolute percent errors of within zero to 25 percent.

FIGURE 1 Algebraic percent errors for employment by Sacramento zones.

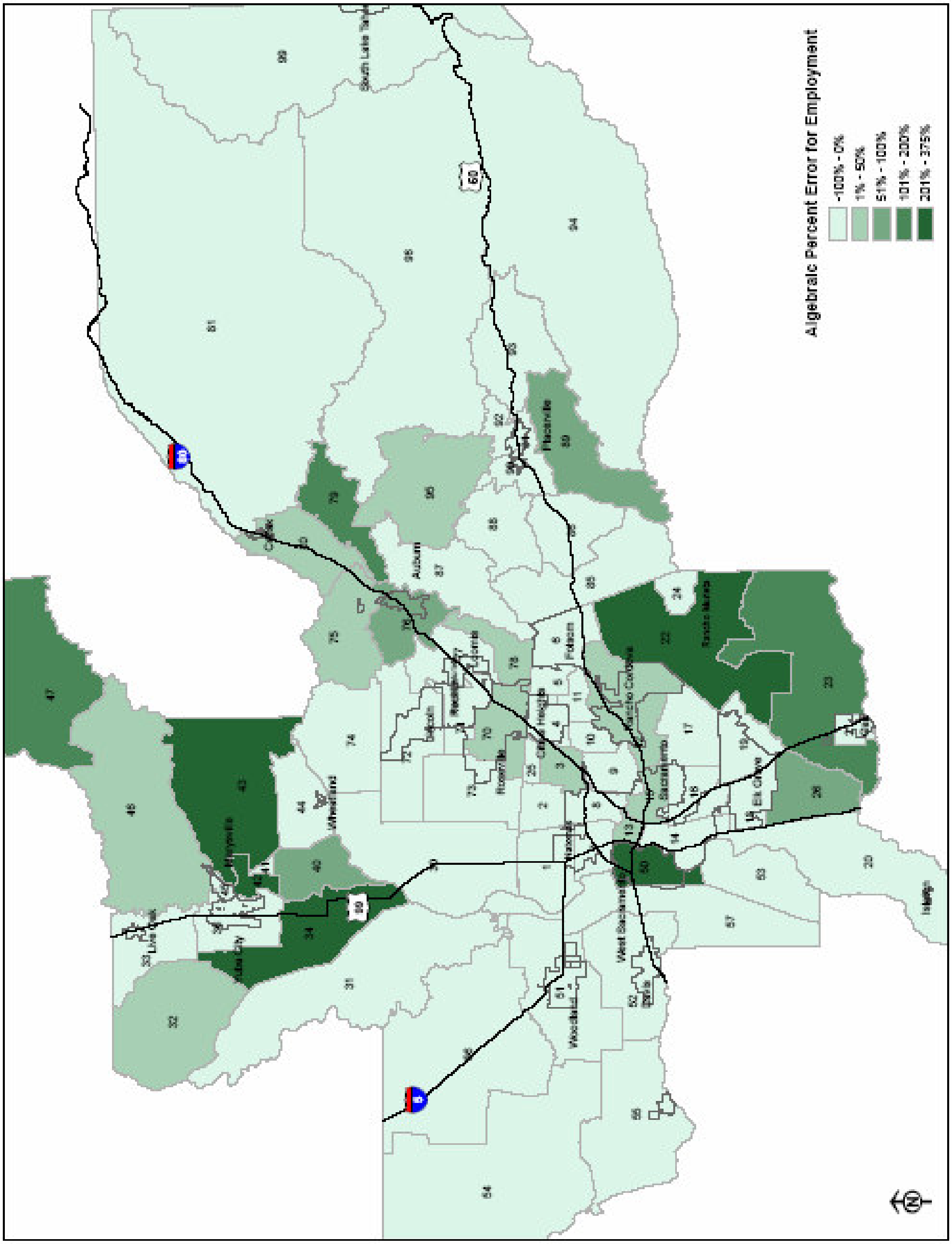
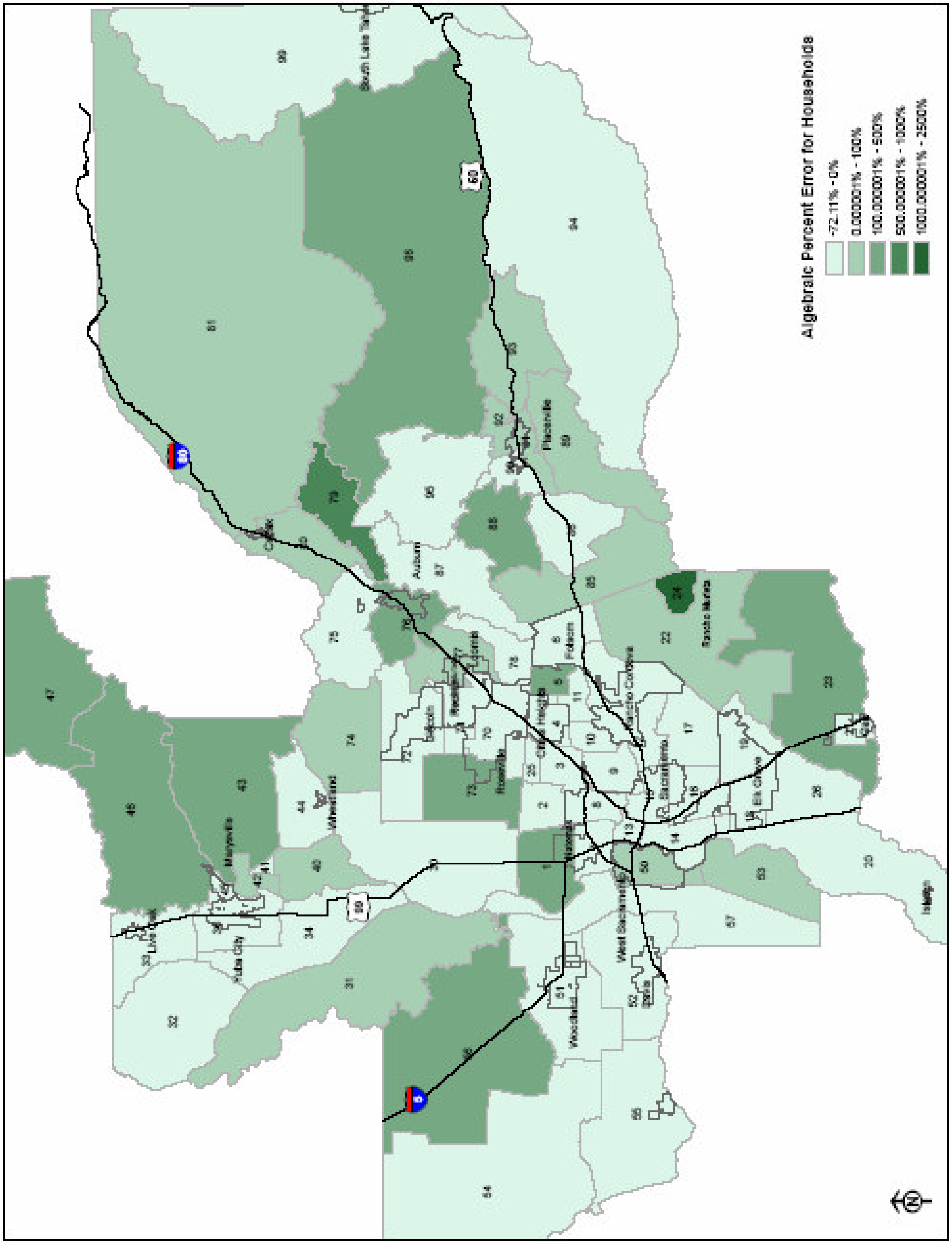


FIGURE 2 Algebraic percent errors for households by Sacramento zones.



The results of the error in the Sacramento MEPLAN's forecast of regional travel for the morning peak period are presented in Table 3. The mode share results indicate relatively high error levels for the transit and bike modes (39 and 105 percent overestimate, respectively) and relatively lower error levels for drive, carpool, and walk modes (11, three, and six percent underestimate, respectively). It appears that these results may be due in part to the overestimate of average vehicle travel times by 14 percent and the underestimate of average vehicle travel speed by four percent. As a result, the model underestimates vehicle trips and vehicle miles traveled by 11 and three percent, respectively.

TABLE 3 Test of model error in travel forecasts

Morning Peak Hour	**Observed**	**Simulated**	**Percent Change**
Model Share			
Drive	39.8%	35.6%	-10.6%
Carpool	45.4%	44.0%	-3.1%
Transit	4.4%	6.1%	38.8%
Walk	6.2%	5.9%	-6.1%
Bike	4.1%	8.4%	104.5%
Vehicle Trips			
Drive	360,306	312,081	-13.4%
Carpool	205,380	192,687	-6.2%
Total	565,688	504,769	-10.8%
Vehicle Miles Traveled			
Drive	3,933,127	3,850,385	-2.1%
Carpool	3,330,132	3,214,317	-3.5%
Total	7,263,260	7,064,703	-2.7%
Mean Vehicle Travel Time (minutes)			
Drive	37.8	45.6	20.7%
Carpool	49.1	51.3	4.4%
Total	41.9	47.8	14.0%
Mean Vehicle Travel Speed (miles per hour)			
Drive	17.3	16.2	-6.4%
Carpool	19.8	19.5	-1.5%
Total	18.5	17.7	-4.0%

Induced Land Use and Travel

In this section, the land use and travel changes induced by the expansion of the regional transportation network from 1990 to 2000 are estimated by simulating the year 2000 holding the 1990 network constant for each future time step (1992 to 2000). The difference between the Forecast 2000 and the Forecast 2000 with the 1990 network is the model's representation of induced demand. The difference between observed data and the Forecast 2000 with the 1990 network adjusted for model error (identified above) is the estimate of actual induced demand.

The magnitude of the induced demand analysis for the zonal land forecasts are presented in Table 4, which depicts the percent of zones within ascending ranges of absolute model and estimated actual induced percent change. Seventy-five percent of zones for households and 85 percent for residential land change fall within the zero to 25 modeled percent change range. There is a wider distribution for non-residential land and employment; 30 and 35 percent of zones fall within the 26 to 50 percent range for employment and non-residential land, respectively. In general, a comparison between the modeled and estimated induced change results suggests that the model tends to overestimate the number of zones with smaller changes and underestimate the number of zones with larger change (ranging from one to 19 percent).

TABLE 4 Percent of zones within absolute model and estimated actual induced percent change by land category

Percent Error Level	Employment		Non-Residential		Households		Residential	
	Model	Estimated	Model	Estimated	Model	Estimated	Model	Estimated
0-25	27%	28%	44%	41%	75%	62%	85%	66%
26-50	30%	15%	35%	18%	14%	14%	7%	20%
51-75	17%	10%	8%	14%	8%	13%	4%	10%
76-100	7%	7%	8%	6%	0%	6%	4%	3%
> 101	20%	39%	4%	21%	3%	6%	0%	1%

The zonal distribution of model and estimated induced algebraic percentage change indicates a positive bias in zonal frequency of algebraic percent induced change; all zones with negative change are less than or equal to 50 percent and most zones (88 to 100 percent) with positive changes are less than or equal to 150 percent.

The disparity in the magnitude of positive and negative algebraic errors provides insight into the pattern of activity allocation that follows from the expansion of the regional transportation network from 1990 to 2000 (largely roadway expansion). Figures 3 and 4 depict the total estimated actual induced change for employment and households. This change (both modeled and estimated actual) tends to reduce employment in more established centers of the region, including the Sacramento's central business district (CBD), West Sacramento, Rancho Cordova, and Roseville. The total employment loss is greatest for Sacramento's CBD (-32,057). Households are typically lost in the older regional suburbs in Arden Arcade, South Sacramento, Citrus Heights, and Orangevale. In general, employment and household activity increase in the outer ring of the region. The total increase in employment is most pronounced in the Elk Grove, South Placerville, West Placerville, El Dorado Hills, Cameron Park, Fair Oaks, Folsom, Loomis, Auburn, and North Sacramento zones. The total increase in households is most pronounced in the Franklin, Laguna, Antelope, Rocklin, and Lincoln zones. Thus, the relatively small negative percent change is associated with larger total zonal losses in more established and populated employment centers and suburbs. These losses are approximately equal to the total gains in the outer ring zones with relatively small initial populations and new suburban housing and employment development.

FIGURE 3 Estimated actual total induced change for employment by Sacramento zones.

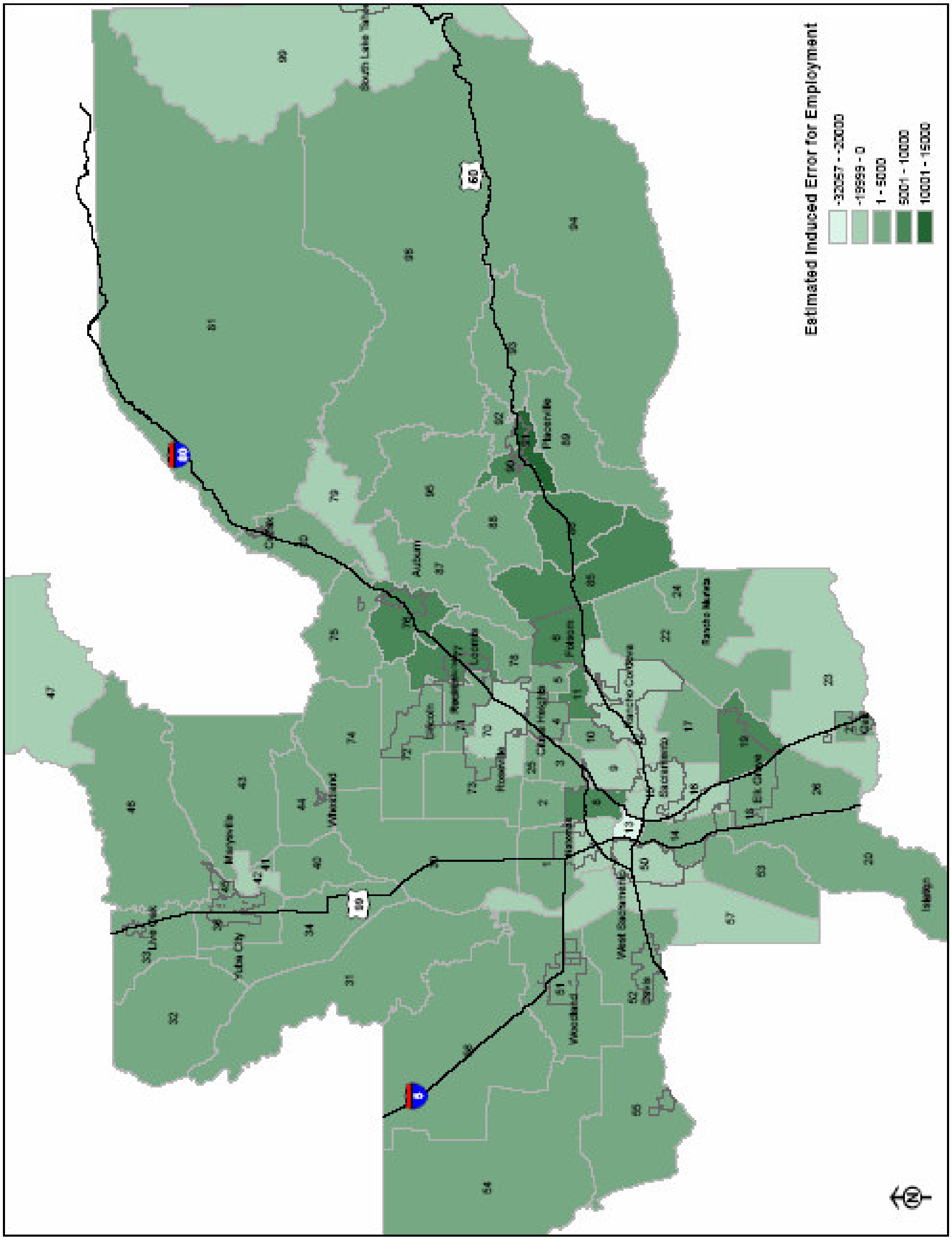
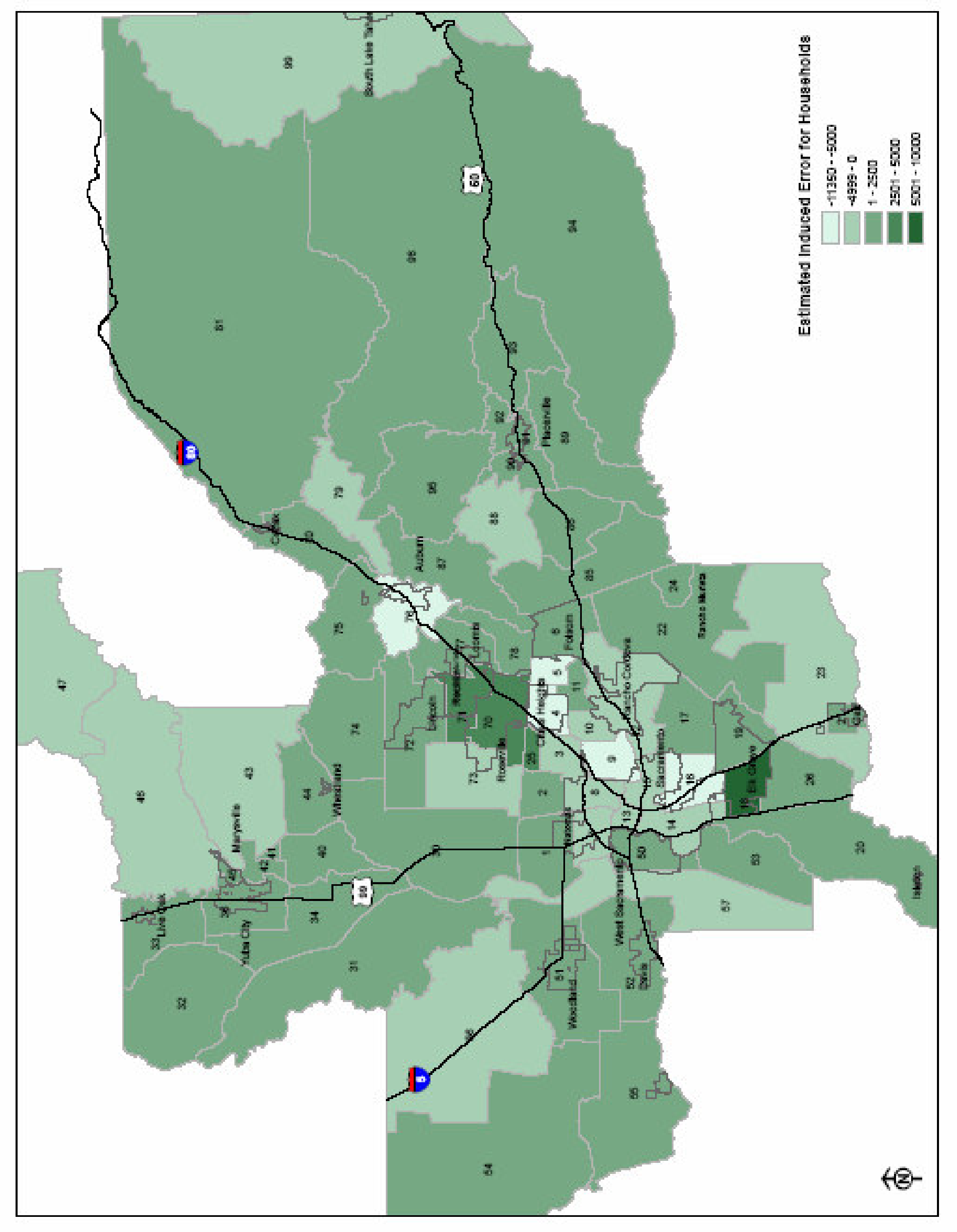


FIGURE 4 Estimated actual total induced change for households by Sacramento zones.



The share of the total absolute induced change in employment and households relative to the total regional population and land development is presented in Table 5. The share for model induced employment and non-residential land is 21 and 32 percent, respectively, and for estimated induced change it is 27 and 30 percent respectively. The share for model-induced households and residential land is 12 and three percent, respectively, and for estimated induced change it is 17 and nine percent respectively. Table 5 also indicates the number of zones that are greater than the absolute value of their model error ("significant" zones) by land category and then share of absolute model-induced change in these zones relative to total regional population and land development. Sixty-five percent of zones are significant for employment and non-residential land forecasts and 31 and 10 percent of zones are significant for households and residential land forecasts, respectively. The share of significant model induced employment and non-residential land is 14 and 21 percent, respectively, and for households and residential land it is three and one percent, respectively. Relative to the regional total, the induced change in employment and non-residential land can be considered relatively large for both total model induced and significant model induced.

TABLE 5 Induced land use change relative to regional total

Absolute Percent	Model-Induced[1]	Estimated Induced[2]	"Significant" Zones [3]	"Significant" Model-Induced[4]
Employment	21%	27%	65%	14%
Non-Residential	32%	30%	65%	21%
Households	12%	17%	31%	3%
Residential	3%	9%	10%	1%

[1] Model-induced is the absolute model-induced change divided by simulated 2000.

[2] Estimated induced change is the absolute estimated induced change divided by observed 2000.

[3] "Significant" zones are the number of zones with model induced change greater than the absolute value of their model error.

[4] "Significant" model-induced change is the absolute change in model-induced travel for only significant zones divided by simulated 2000.

The induced demand analysis of travel is presented in Table 6. The moderate roadway and highway expansion in the region over the ten-year period produces a reduction in average vehicle travel time (7.6 percent) and an increase in average travel speed (15.7 percent) leading to a modest increase in vehicle trips (one percent) and a larger increase in vehicle miles traveled (VMT) (4.5 percent). The elasticity of vehicle miles traveled with respect to travel time and travel speed are consistent with those reported in the empirical literature for a short-term time horizon (-0.58 and 0.28, respectively). A comparison of the model-induced travel results to the estimated actual induced travel results indicates that the model may underestimate induced travel effects somewhat for vehicle trips, vehicle miles traveled, and vehicle travel speed and overestimate the reduction in travel speed. Importantly, however, the regional induced travel results for vehicle miles traveled, mean vehicle travel times, and mean vehicle travel speed fall outside of the absolute value of the error levels established in Table 6. As a result, the results may be considered significant with respect to model errors.

TABLE 6 Analysis of induced travel results

Vehicle Travel	**Model Induced**	**Estimated Induced**
Vehicle Trips	-0.12%	1.05%
Vehicle Miles Travel	4.38%[1]	4.46%[1]
Mean Vehicle Travel Time	-9.44%[1]	-7.62%[1]
Mean Vehicle Travel Speed	15.52%[1]	15.71%[1]
Elasticity of VMT/Travel Time	-0.46[1]	-0.58[1]
Elasticity of VMT/Travel Speed	0.28[1]	0.28[1]

[1] Indicates that the absolute change is greater than the absolute value of the model error.

CONCLUSION

The results of this case study have three key policy implications with respect to air quality conformity and environmental impact analyses. First, if the model were used in conformity analyses, then the regional transportation plan emissions analysis should fall outside the three percent model error underestimate (e.g., assuming VMT ranks with emissions) to demonstrate conformity. Second, if the model were used for the analysis of travel effects of proposed highway investment projections in environmental impact statements, then the overestimation of the daily travel results would tend to underestimate no-build travel demand and congestion and thus underestimate the need for new highway projects in the region. Compared to point estimates for the no-build alternative, the magnitude of change for the highway alternative should be greater than the absolute value of model error to be considered a significant improvement to the no-build alternative. Third, for both conformity and environmental impact analyses, the results of this study indicate that land use changes from a new project may be significant and thus should be included in valid evaluations as required by current legislation and regulations.

The results of this case study also illustrate how validation tests can be used to improve the application of models in the policy process in general. If the users of model results are aware of the model's uncertainty, then the focus of the analysis may shift from meeting a point estimate of demand for travel in a particular corridor and toward the rank ordering of a number of alternative policy strategies. It may be far more defensible to use an uncertain model to compare competing alternatives rather than projecting and meeting a particular point estimate as long as the model's structure is not biased toward particular modes or policies. The evaluation of a range of alternatives is more likely to address stakeholder concerns and encourage innovative thinking about the future. Candid representation of the uncertainty in models may address the stakeholders' concerns about the limitations of models and help refocus debates away from technical modeling issues to more careful consideration and planning to address air quality and transportation problems.

ACKNOWLEDGEMENTS

The author would like to thank John Abraham at the University of Calgary and Gordon Garry at the Sacramento Regional Council of Governments for their invaluable assistance on technical modeling questions, identification of data, and comments. Without their help, this study would not have been possible. She would also like to thank Dr. J. M. Pogodzinski of San José State University for his comments on the final version of the draft. Thanks are also offered to the Environmental Protection Agency for their support of this work. Additional thanks are offered to MTI staff, including Research Director Trixie Johnson, Research and Publications Assistant

Sonya Cardenas, Webmaster Barney Murray, Graphic Artists Shun Nelson and Tin Yeung, and Editorial Associate Catherine Frazier for editing and publication assistance. The contents of this paper reflect the views of the author and do not necessary indicate acceptance by the sponsors.

REFERENCES

1. "Travel Demand Model Peer Review." Wasatch Front Regional Council Summary of Proceedings, Salt Lake City, UT. May 18-19, 1999.

2. "Summary of GRTA Performance Measure and Alternatives Analysis Workshop Session." Report workshop to look at modeling, performance measures, and alternatives for Georgia Regional Transportation Authority, Atlanta, GA. August 5, 1999.

3. Abraham, J.E., G.E. Garry, and J.D. Hunt. "The Sacramento PECAS model." Preprint for Transportation Research Board Annual Meeting, Washington, DC. January, 2005.

4. Condor, S. and K. Lawton. "Alternative Futures for Tansportation and Land Use–Integrated Models Contrasted with 'Trend Delphi' Methods: The Portland Metro Results," *Transportation Research Record 1805*, 2002. pp. 99-107.

5. Rodier, Caroline J. *Uncertainty in Travel and Emissions Models: A Case Study in the Sacramento Region (*Ph.D. Dissertation, University of California, Davis, 2000).

6. Marshall, N. and B. Grady. *Draft Induced Travel Results*. Resource Systems Group for the U.S. Environmental Protection Agency, 2001.

7. A. Pradhan, A. and K. Kockelman " Uncertainty propagation in an integrated land use-transportation modeling framework: output variation via UrbanSim," *Transportation Research Record 1805,* 2002. pp 128-135.

8. Rodier, Caroline J. "A multi-objective analysis of regional transportation and land development policies," Preprint for Transportation Research Board Annual Meeting, Washington, DC. January, 2005.

9. Waddell, P. "UrbanSim: Modeling urban development for land use, transportation, and environmental planning," *Journal of the American Planning Association*, 68:3, Summer 2002. pp. 297-314.

10. Johnston, R. A., C. J. Rodier, J. E. Abraham, and J.D. Hunt. *Applying an Integrated Model to the Evaluation of Travel Demand Management Policies in the Sacramento Region: Year Two.* MTI Report 01-08, September 2001.

11. Abraham, J.E. and J.D. Hunt, "Calibrating the MEPLAN model of Sacramento," Transportation Research Board Annual Meeting, Washington DC. January 1998. paper 980649.

12. Abraham, J.E. and J.D. Hunt, "Semi-automated calibration of the MEPLAN model of

Sacramento," proceedings of the 6th Computers in Urban Planning and Urban Management conference in Venice, Italy in September, 1999.

13. Abraham, J.E. and J.D. Hunt, "Policy Analysis using the Sacramento MEPLAN Land Use Transportation Interaction Model," *Transportation Research Record* 1685:199-208 and presented at the 1999 annual meeting of the *Transportation Research Board.*

14. Abraham, J.E. and J.D. Hunt, "Firm Location in the MEPLAN model of Sacramento." *Transportation Research Record* 1685:187-198 and presented at the 1999 annual meeting of the *Transportation Research Board.*

15. Abraham, J.E. *Parameter Estimation in Urban Models: Theory and Application to a Land Use Transport Interaction Model of the Sacramento, California Region* (Ph.D. Dissertation, Department of Civil Engineering, University of Calgary, 2000).