



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



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

October 2005

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16. Abstract Governmental bodies in the United States are implementing more advanced land use and travel demand models to meet air quality conformity and environmental impact statement requirements. To help guide model applications in policy studies, this report describes an evaluation of model accuracy and induced demand representation over a 10-year period in an integrated land use and transportation model, the 2000 Sacramento MEPLAN model. The accuracy evaluation shows relatively high error levels for zonal land use forecasts. More zones have lower percentage errors for employment and nonresidential land forecasts (56 and 34 percent, respectively, within +50 percentage points) relative to household and residential land forecasts (14 and 18 percent, respectively, within +50 percentage points). There are smaller errors in established central urban areas and larger errors in the outer ring. The model underestimates average vehicle travel speeds by 4 percent and vehicle miles traveled by 3 percent. Induced demand analysis shows that new transportation capacity produced absolute percent changes in the zero to 25 percent range for 75 and 85 percent of zones for households and residential land, respectively, and in the 26 to 50 percent range for 30 and 35 percent of zones for employment and nonresidential land, respectively. Relative to estimated actual induced travel, the model overestimated the number of zones with smaller changes and underestimated the number of zones with larger changes (1 to 19 percent). Total estimated actual induced change by zone showed losses in older employment and suburban regional centers and gains in the outer ring. The share of significant model-induced employment and nonresidential land (greater than zonal absolute model error) relative to the regional total was 14 and 21 percent, respectively; 3 percent for households; and 1 percent for residential land. Roadway expansion increased vehicle miles traveled 5 percent and average travel speed 16 percent with 0.28 elasticity. Using the model for conformity analysis, the regional transportation plan emissions analysis should fall outside model error to demonstrate conformity. In environmental impact analyses of new roadway projects, model errors tended to underestimate no-build travel and project need. The magnitude of change from the no-build alternative to the highway alternative should be greater than the absolute value of model error to be a significant improvement. For both conformity and environmental impact analyses, this study indicates that land use changes from a new project may be significant and should be included in valid evaluations as required by current regulations.			
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TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
INTRODUCTION	5
LITERATURE REVIEW	7
TESTS OF THE SIGNIFICANCE OF THE LAND USE EFFECT	7
SENSITIVITY TESTS OF UNCERTAINTY FROM INPUT DATA AND PARAMETER ERROR	7
VALIDATION STUDIES OF MODEL ACCURACY	8
METHODS	9
THE SACRAMENTO MEPLAN MODEL	9
VALIDATION TESTS	9
OBSERVED DATA	14
RESULTS	15
TEST OF MODEL ERROR	15
INDUCED LAND USE AND TRAVEL	21
CONCLUSION	29
ENDNOTES	33
ABBREVIATIONS AND ACRONYMS	35
BIBLIOGRAPHY	37
ABOUT THE AUTHOR	39
PEER REVIEW	41

LIST OF FIGURES

1. Algebraic Percent Errors for Employment by Sacramento Zones	17
2. Algebraic Percent Errors for Households by Sacramento Zones	18
3. Percent of Zones Less Than or Equal to Absolute Percentage Error by Land Category	19
4. Zonal Distribution of Model Algebraic Induced Percent Change	22
5. Zonal Distribution of Estimated Algebraic Induced Percent Change	22
6. Estimated Actual Total Induced Change for Employment by Sacramento Zones	24
7. Estimated Actual Total Induced Change for Households by Sacramento Zones	25

LIST OF TABLES

1. Modifications to Sacramento MEPLAN Input Files for Tests of Model Accuracy and Induced Demand	10
2. Description of Forecasts Used in Validation Tests	11
3. Percent of Zones with Mean Algebraic Percent Error + 10 to 100 Percentage Points by Land Category	15
4. Percent of Zones Less Than or Equal to Absolute Percentage Error by Land Category	19
5. Test of Model Error in Travel Forecasts	20
6. Percentage of Zones Within Absolute Model and Estimated Actual Induced Percentage Change by Land Category	21
7. Induced Land Use Change Relative to Regional Total	26
8. Analysis of Induced Travel Results	27

EXECUTIVE SUMMARY

State and regional governments across the United States are implementing more advanced land use and travel demand models to meet air quality conformity (1990 Clean Air Act regulations) and environmental impact statement (National Environmental Policy Act) requirements. To guide applications of these models in policy studies better, this report describes an evaluation of model accuracy and induced demand representation over a 10-year period in the 2000 Sacramento MEPLAN model, an integrated land use and transportation model.

To evaluate accuracy, this study includes a simulation of year 2000 land use and travel that uses, as inputs, 1990 observed zonal land use data, observed regional growth estimates from 1990 to 2000, and observed changes in the regional transportation network from 1990 to 2000. This forecast is compared to observed 2000 land use and travel data to identify the magnitude of model error from errors in model functional forms and parameter specifications.

The induced demand analysis in this study includes a simulation of the year 2000 land use and travel in which the 1990 transportation network is held constant to the year 2000. The results are compared to the 2000 forecast and the 2000 transportation network to identify the model's representation of induced travel. The results are also compared to observed 2000 land use and travel data to estimate actual induced travel over the 10-year period.

The model accuracy evaluation indicates relatively high levels of percentage errors for zonal land use forecasts. Approximately 72 to 85 percent of the zones across the land use categories fall within plus/minus 100 percentage points. More zones have lower percentage errors for the employment and nonresidential land forecasts (56 and 34 percent, respectively, within plus/minus 50 percentage points) relative to the household and residential land forecasts (14 and 18 percent, respectively, within plus/minus 50 percentage points).

In general, there are relatively modest percentage errors (less than 50 percent) for zones in the more established urban areas in the region, including Sacramento's central business district, Rancho Cordova, and Roseville. Larger errors are found in the outer areas of the region, where the model tends to overestimate the location of households and employment. These errors may result from a developer model with limited sensitivity to prices set too low. It is also possible that the large zones in the outer regions tend to underestimate travel

times because so much of their transportation system is abstracted into high-capacity centroid connectors, leading to overestimates of household and employment location. The model's representation of land-use trends over time may be improved by calibrating the model to two different points in time (for example, 2, 5, or 10 years apart).

The regional travel model error results indicate an overestimation of average vehicle travel times (14 percent) and an underestimation of average vehicle travel speeds (4 percent) and vehicle miles traveled (3 percent).

The induced demand analysis shows that moderate roadway capacity expansion over the 10-year period produces absolute percentage change in the zero to 25 percent range for 75 and 85 percent of zones for households and residential land, respectively, and in the 26 to 50 percent range for 30 and 35 percent of zones for employment and nonresidential land, respectively. Relative to the estimated actual induced travel, the model tends to overestimate the number of zones with smaller changes and underestimate the number of zones with larger changes (ranging from 1 to 19 percent). The regional maps of total estimated actual induced change show employment losses in more established centers of the Sacramento region, household losses in the older regional suburbs, and employment and household activity increases in the outer ring. For employment and nonresidential land forecasts, 65 percent of zones could be considered significant (or greater than the absolute value of zonal model error by land category); 31 and 10 percent of zones may be significant for households and residential land forecasts, respectively. The share of significant model-induced employment and nonresidential land relative to the regional total is 14 and 21 percent, respectively, and for households and residential land, it is 3 and 1 percent, respectively. The significant induced change in employment and nonresidential land can be considered large relative to the total regional population and the magnitude of the roadway capacity expansion projects over the 10-year period.

The roadway expansion also reduces average vehicle travel time (7.6 percent) and increases average travel speed (15.7 percent) and vehicle miles traveled (4.5 percent). The elasticity of vehicle miles traveled with respect to travel time and speed is consistent with what has been reported in the empirical literature for shorter-term time horizons (-0.58 and 0.28, respectively). The regional induced travel results for vehicle miles traveled, mean vehicle travel times, and mean vehicle travel speed fall outside the absolute value of model error levels and thus may be considered significant.

The results of this case study have three key policy implications with respect to air quality conformity and environmental impact analyses:

1. To use the model in conformity analyses, the regional transportation plan emissions analysis should fall outside the 3 percent model error underestimate (for example, assuming VMT ranks with emissions) to demonstrate conformity.
2. For the analysis of travel effects of proposed highway investment projections in environmental impact statements, 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.
3. 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.

Validation tests can be used to improve the application of models in the policy studies and in the policy process in general. Making a model's uncertainty explicit may alert the public and decision makers to potential problems and enable them to take steps now to avoid harmful future effects.

In the context of air quality conformity, if validation tests of a region's travel demand model show a downward bias in the model, the region may want to ensure that it meets emissions budgets by an appropriate margin. This may involve more aggressive implementation of emission reduction measures (for example, technology-based strategies, land use measures, transit investment, and pricing policies) and reconsideration of new highway projects.

In the context of the National Environmental Policy Act (NEPA) process and, in particular, the analyses of proposed highway investments in environmental impact statements, if the users of model results are aware of the model's uncertainty, 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.

Local interest groups have become increasingly suspicious of models used by metropolitan planning organizations in their conformity analyses and environmental impact statements. Such groups are concerned that models do not adequately represent induced travel and thus underestimate emissions effects of regional transportation plans that include new roadways or bias the analysis of alternatives in environmental impact statements in favor of roadway projects. Some are even concerned that underlying assumptions in the model are manipulated to make results meet emissions budgets or to make the proposed projects (generally roads) in environmental impact statements look beneficial.

As a result, there can be numerous technical debates and, ultimately, lawsuits over the adequacy of travel demand models that arise in both the air quality conformity and the NEPA processes. 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.

INTRODUCTION

United States legislation and regulations mandate that planning agencies analyze the relationship between land use and transportation decisions. The U.S. Environmental Protection Agency's conformity regulations for the Clean Air Act Amendments (CAAA) of 1990 require a logical correspondence between future regional land use projections and transportation plans in serious or worse nonattainment 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 in environmental impact statements. The 1998 Transportation Equity Act for the 21st Century (TEA-21) urges that transportation plans consider the effects of transportation policy decisions on land use and economic development. Peer reviews of travel demand models in regions with air quality problems and plans for significant freeway expansions increasingly recommend that regional planning agencies represent the effect of their transportation plans on land uses (for example, Salt Lake City, Utah,² and Atlanta, Georgia³).

The questions surrounding the land use effects of transportation investment decisions that TEA-21 and CAAA ask planning agencies to answer are also raised by the public in local meetings in regions where major transportation investments are proposed. For example, many regions are considering new beltway freeways and major transit investments, and groups with diverse interests want to know what effect these projects will have on land development, the future location of employment and households, and the local economy.

Driven by the factors described above, state and regional governments across the United States are implementing more advanced land use models with travel demand models and integrated land use and transportation models. These include the UrbanSim model developed by Paul Waddell in the Eugene/Springfield region of Oregon and in Salt Lake City; the integrated TRANUS model⁴ in Baltimore, Maryland; an adapted statewide TRANUS model in Oregon;⁵ and the integrated MEPLAN⁶ in Sacramento, California.

The more widespread practice of most regional planning agencies in the United States is to develop a single set of land use projections for each time horizon used in their travel and emissions models. The consensus-based process includes gathering data such as building permits and general plans from local jurisdictions and incorporating the long-range expectations of planners and politicians.⁷ This approach does not adequately represent the effect of transportation plans on the future location of employment and population and is

subject to numerous inaccuracies and biases.⁸ For example, the 10-year historical validation study of the Sacramento regional travel demand model found that errors in the model's consensus-based land use projections approximately doubled the model's errors (those that resulted from functional forms and parameters only) in vehicle travel.⁹

Land use models, however, are subject to many of the same sources of inaccuracy as travel demand models. Given the complexity of these models, they may be as uncertain as travel demand models, or even more so. Theoretical improvements in the land use and transportation representation could be swamped by other errors in a more complex model set.

To improve applications of these models in policy studies, this report describes an evaluation of model accuracy and induced demand representation over a 10-year period in an integrated land use and transportation model, the 2000 Sacramento MEPLAN model. The model is being used by the region's metropolitan planning organization (MPO) for land use projections as a temporary model, while a new PECAS model is being calibrated and deployed.¹⁰

The model accuracy evaluation includes a simulation of year 2000 land use and travel that uses, as inputs, 1990 observed zonal land use data, observed regional growth estimates from 1990 to 2000, and observed changes in the regional transportation network from 1990 to 2000. This forecast is compared to observed 2000 land use and travel data to identify the magnitude of model error resulting from errors in model functional forms and parameter specifications.

The induced demand analysis includes a simulation of year 2000 land use and travel, in which the 1990 transportation network is held constant to the year 2000. The results are compared to the 2000 forecast and the 2000 transportation network to identify the model's representation of induced travel. The results are also compared to observed 2000 land use and travel data to estimate actual induced travel over the 10-year period.

The results of the model error and induced travel analysis of the Sacramento MEPLAN model provide insights into the accuracy of land use and transportation models and how uncertain land use and travel models may be best applied in policy studies.

LITERATURE REVIEW

TESTS OF THE SIGNIFICANCE OF THE LAND USE EFFECT

A few studies address the potential benefits of a theoretically improved model set that represents the land use and transportation interaction. Condor and Lawton compare the results of travel demand model simulations for a future transportation plan that uses typical, consensus-based land use projections and land use projections from a land use model linked iteratively with a travel demand model. The comparison shows that congestion and the long-term need for transportation investment are overstated when the land use model is not linked to the travel demand model.¹¹

Rodier 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. The failure to represent the interaction in highway scenarios produces relatively large changes: land use change induced by the highway expansion accounts for approximately 50 percent of the induced travel.¹²

Marshall and Grady conduct a sensitivity analysis of the land use and travel demand model set used by the MPO in Chittenden County (Burlington, Vermont). Comparing scenarios in which the land use effects of the build scenario are held constant and allowed to vary shows that change in land uses has little effect on travel results. The authors state that “these results may be specific to the conditions modeled, which include relatively rapid growth in population and employment with very little increased roadway capacity in the Build condition” and that “under these conditions, it appears that the land use allocation model may be acting as a brake on land use decentralization in both the No-Build and the Build cases.”¹³

SENSITIVITY TESTS OF UNCERTAINTY FROM INPUT DATA AND PARAMETER ERROR

Two recent studies evaluate the effect of input data and parameter errors in land use models on their forecasts. Pradhan and Kockelman apply Monte Carlo methods to the UrbanSim model “to model uncertainty in demographic inputs (which include aggregate growth rates and mobility rates) to the land use model, as well as uncertainty in various model parameters.” The results suggest 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).”¹⁴

Rodier conducted a sensitivity analysis with plausible errors in total population, fuel price, and income projections using an earlier version of the Sacramento MEPLAN model. The results indicate that plausible error ranges are important sources of uncertainty in the model’s land development results but are less important in the model’s travel results; for a range of scenarios, land use projections are less likely to fall outside, and travel models more likely to fall inside, a 95 percent confidence interval.¹⁵

VALIDATION STUDIES OF MODEL ACCURACY

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 conducted 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 improved, so did the goodness-of-fit (results for cells ranged from 0.45 to 0.64 and from 0.64 to 0.88 for zones).¹⁶

Rodier conducted a historical validation study of a regional travel demand model in the Sacramento region. The original 1991 version of the model uses 2000 observed data to validate the model over a nine-year period. The results indicate that the 1991 model overestimates vehicle miles traveled (5.7 percent), vehicle hours traveled (4.2 percent), and vehicle hours of delay (17.1 percent), that errors in land use projections approximately double these errors, and that the model underestimates induced travel.¹⁷

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 more than 20 years and is readily available for calibration; however, the Sacramento MEPLAN model is the first application in the United States. The Sacramento MEPLAN model (version 3e) represents the regional economy and land market, redevelopment, and 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 (MTI) funded key improvements to the model, and 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 (that is, 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 MTI Report 01-08¹⁸ and in numerous published papers.¹⁹

VALIDATION TESTS

When developing a travel demand model, the model is estimated on local data, 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 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. Such tests will provide insight into the degree of precision with which models can be applied in policy studies that rely on absolute model accuracy, such as point estimates of emissions budgets or level of roadway service. For

example, if the results of model validation tests indicate that the model's predictions differ from actual data by some percent (for example, plus/minus 10 percent), and the results of an alternative policy scenario fall within that error range (for example, plus/minus 5 percent), there is a significant probability that the alternative policy scenario may exceed the point estimate (for example, produce emissions greater than the emissions budget or reduce roadway level of service).

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 10-year period. Table 1 describes the modifications made to MEPLAN input files for the study.

Table 1 Modifications to Sacramento MEPLAN Input Files for Tests of Model Accuracy and Induced Demand

Years (s)	MEPLAN File Name & Description	Modifications
1990	ULC (1): Production constraints for activities (household, employment, and land use) by type by zone.	1990 observed data provided by SACOG.
1990	ULC (2): Exogenously produced changes (production and attractions) for activities by type by zone.	Applied 2000 Sacramento MEPLAN model parameters to 1990 observed data provided by SACOG.
1992-97	ULC (3): Global changes in exogenous production and minimum and maximum production constraints for time increment (90-92, 92-95, 95-97, and 97-00) by type across internal zones.	Applied 2000 Sacramento MEPLAN model parameters to observed 1990-2000 data to develop exogenous production and attraction factors by type across internal zones.
1990	ULI: Acres of vacant and developed land by type.	Subtracted acres of developed land from ULC (1), described above from year 2000 vacant land data by type. Note that accurate inventories for 1990 vacant and developed land were not available.
1990-97	UTN: Highway and transit network. Converted from SACOG travel model network to use Sacramento MEPLAN zone system.	Compared 1990 to 2000 SACOG travel model networks to identify additions and deletions over 10-year period. Conducted expert interviews with SACOG staff to verify additions and deletions by model time steps.

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 2. The land use and travel results from Forecast 2000 are compared to available observed 2000 data to assess model error.

Table 2 Description of Forecasts Used in Validation Tests

Forecasts	Network	Input Land Use
Model Accuracy Forecast 1 (F ¹ or Forecast 2000)	1990 1992 1995 1997 2000	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 or Forecast 2000 with 1990 network)	1990 (for all model time steps, including 1992, 1995, 1997, and 2000)	1990 observed households, employment, vacant land, and developed land by zone 1990-2000 observed regional population and employment growth

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

$$ALE_i = F^1_i - O^1_i \quad (1)$$

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 (for example, total regional mode share, VMT, or travel time). The mean algebraic error (MALE), where n is equal to the total number of zones, is calculated as:

$$MALE = (\sum ALE_i)/n. \quad (2)$$

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

$$ALPE_i = (ALE_i / O_i^1) * 100 \quad (3)$$

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

$$MALPE = (\sum ALPE_i) / n \quad (4)$$

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 2. The only difference between this simulation and Forecast 2000 in the model accuracy test is the use of the year 1990 roadway and transit network in all time steps through the year 2000. The major roadway network expansion from 1990 to 2000 includes new HOV lanes along State Route 99 from downtown Sacramento to Elk Grove; two new interchanges on I-5 at Laguna and Elk Grove Boulevards 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 on page 17 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 also was expanded east of Sacramento from downtown during this time.

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 *model* algebraic change (MALC) is calculated as:

$$MALC_i = F_i^1 - F_i^2 \quad (5)$$

where F_i^1 is the Forecast 2000 value, F_i^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 (for example, total regional mode share, VMT, or travel time). Next, the *model* algebraic percent change (MALPC) is calculated as:

$$MALPC_i = (MALC_i / F_i^2) * 100 \quad (6)$$

The absolute value of the $MALPC_i$ ($/MALPC_i/$) is the *model* absolute percent change ($MAPC_i$).

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. The correction is approximate because the 1990 network 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:

$$EALC_i = O^1_i - (F^2_i(1 - ALPE_i)) \quad (7)$$

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:

$$EALPC_i = (EALC_i / (F^2_i(1 - ALPE_i))) * 100. \quad (8)$$

The absolute value of the $EALPC_i$ ($/EALPC_i/$) is used to calculate the *estimated* absolute percentage change ($EAPC_i$).

OBSERVED DATA

The socioeconomic data used in the simulation studies were developed by SACOG with annual housing and triannual 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. This type of data often is 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. They are estimates, rather than counts, and thus there is potential for measurement error. It is also possible that zoning restrictions in the model, as represented in the zonal land inventory, may contain errors. The magnitude or direction of these potential errors cannot be quantified; 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

The distribution of zones with plus/minus 10 to 100 percentage points of their mean algebraic percent error are depicted in Table 3. These results indicate that approximately 72 to 85 percent of the zones across the land use categories fall within plus/minus 100 percentage points. More zones have lower algebraic errors for the employment and nonresidential land forecasts (56 and 34 percent, respectively, within plus/minus 50 percentage points) relative to the household and residential land forecasts (14 and 18 percent, respectively, within plus/minus 50 percentage points).

Table 3 Percent of Zones with Mean Algebraic Percent Error + 10 to 100 Percentage Points by Land Category

Percentage points	Employment (7% ^a & -240 ^b)	Nonresidential 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%

a. MALPE (mean algebraic percent error) b. MALE (mean algebraic error)

The distribution of the algebraic percent errors are positively biased across all land categories with means ranging from 7 to 86 percent. However, the algebraic errors are negatively biased for employment and household forecasts (-240 and -190, respectively) and positively biased for nonresidential and residential acres (30 and 62, respectively). The

global production changes to exogenous production estimated with observed data appear to have underestimated total regional households and employment by almost 2 percent and overestimated total regional residential and nonresidential land development by 25 and 15 percent, respectively. In general, zones with relatively small initial values were just as likely as zones with relatively large initial values to have high algebraic percent errors.

Algebraic percent errors for employment and households are depicted in Figure 1 and Figure 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 0 percent). There are relatively modest errors (less than 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 (for example, 2, 5, or 10 years apart) to improve the model's representation of land use trends over time. The data used in this validation study could be used to improve model calibration over time.

The accuracy of the land forecasts are examined in Table 4 and Figure 3, which depict the share of the total number of zones less than or equal to the absolute percentage error. Eighty percent of the zones have absolute percentage errors for employment and households within zero to 75 percent and for nonresidential and residential land within zero to about 110 percent. Thirty percent of zones for employment and nonresidential land and 50 percent of zones for households and residential land have absolute percent errors within zero to 25 percent.



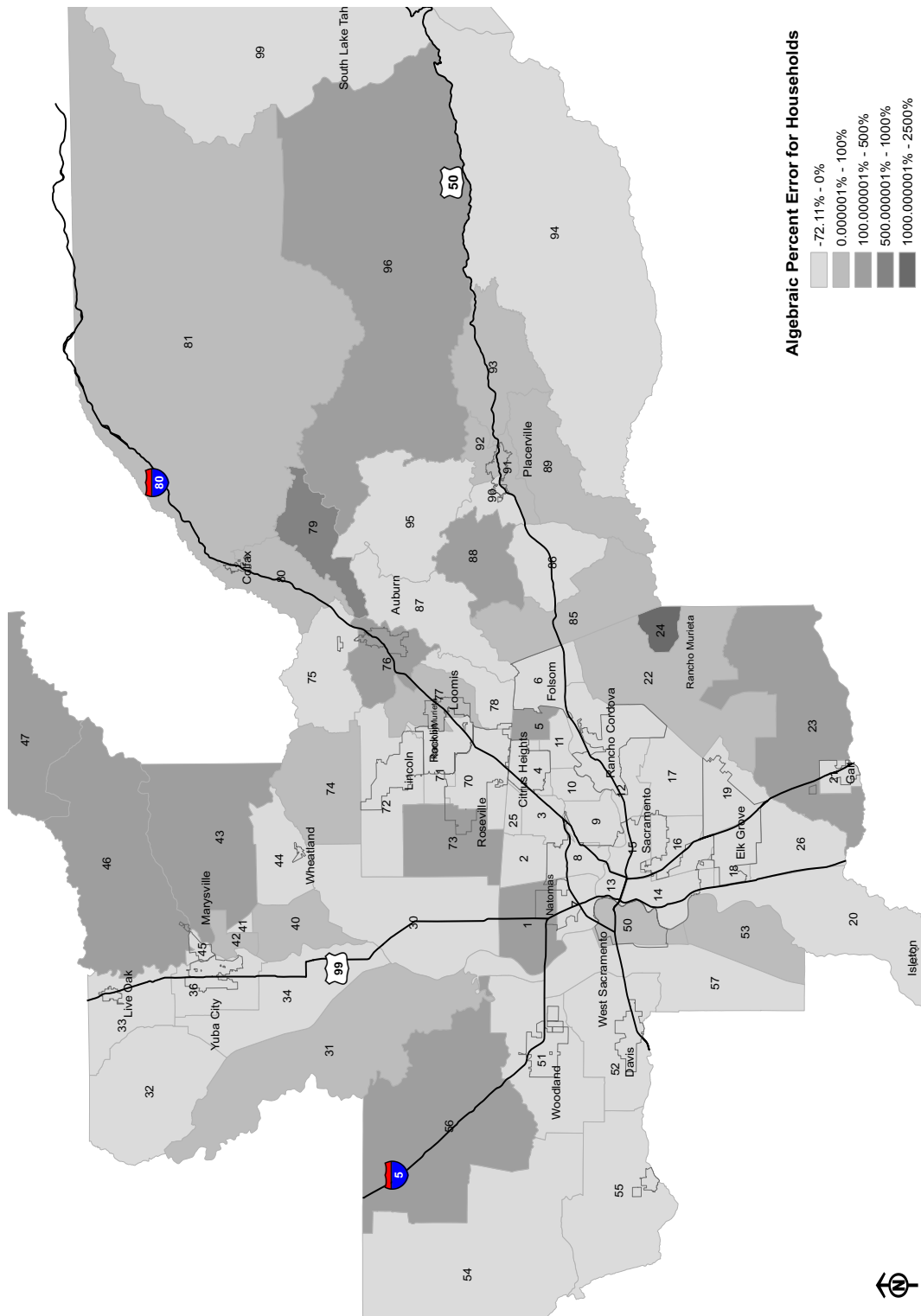


Figure 2 Algebraic Percent Errors for Households by Sacramento Zones

Table 4 Percent of Zones Less Than or Equal to Absolute Percentage Error by Land Category

Percent of Zones	Employment	Nonresidential Land	Households	Residential Land
10%	6%	6%	4%	1%
20%	13%	16%	12%	4%
30%	24%	22%	16%	7%
40%	31%	33%	18%	14%
50%	38%	45%	24%	25%
60%	47%	56%	31%	37%
70%	58%	87%	44%	55%
80%	77%	112%	72%	108%
90%	101%	269%	172%	203%

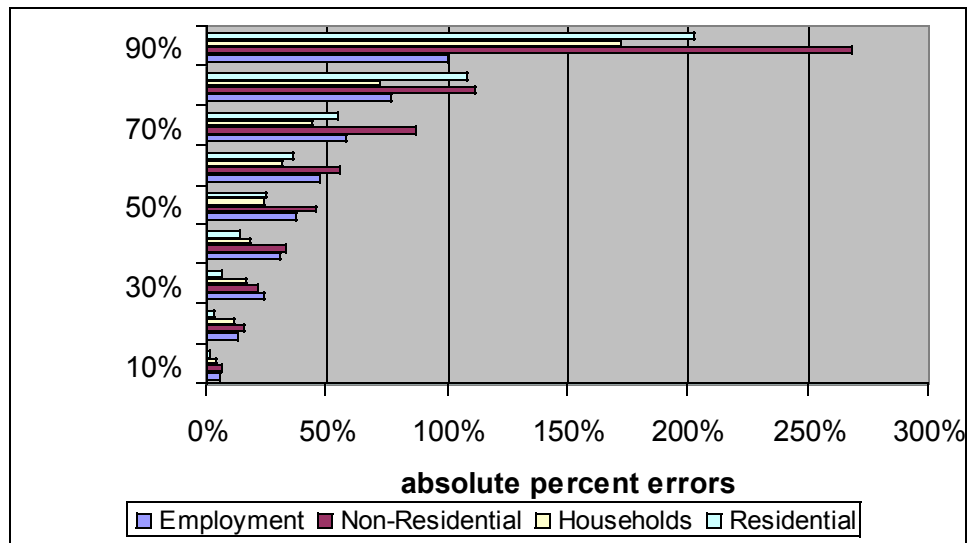


Figure 3 Percent of Zones Less Than or Equal to Absolute Percentage Error by Land Category

The results of the error in the Sacramento MEPLAN's forecast of regional travel for the morning peak period are presented in Table 5. The mode share results indicate relatively high error levels for the transit and bike modes (39 and 105 percent overestimated, respectively) and relatively lower error levels for drive, carpool, and bike modes (11, 3, and 6 percent underestimated, respectively). These results may result in part from the overestimation of average vehicle travel times (by about 14 percent) and the underestimation of average vehicle travel speed by (about 4 percent). As a result, the model underestimates vehicle trips and vehicle miles traveled by 11 and 3 percent, respectively.

Table 5 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%

Table 5 Test of Model Error in Travel Forecasts (Continued)

Morning Peak Hour	Observed	Simulated	Percent Change
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

The magnitude of the induced demand analysis for the zonal land forecasts is presented in Table 6, which depicts the percentage of zones within ascending ranges of absolute model and estimated actual induced percentage change. Seventy-five percent of zones for households and 85 percent for residential land change fall within the zero to 25 modeled percentage change range. Nonresidential land and employment have a wider distribution: 30 and 35 percent of zones are in the 26 to 50 percent range for employment and nonresidential 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 changes (from 1 to 19 percent).

Table 6 Percentage of Zones Within Absolute Model and Estimated Actual Induced Percentage Change by Land Category

Error Level	Employment		Nonresidential		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 percent change by land category is illustrated in Figure 4 and Figure 5. These figures indicate 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 88 to 100 percent of zones with positive changes are less than or equal to 150 percent.



Figure 4 Zonal Distribution of Model Algebraic Induced Percent Change



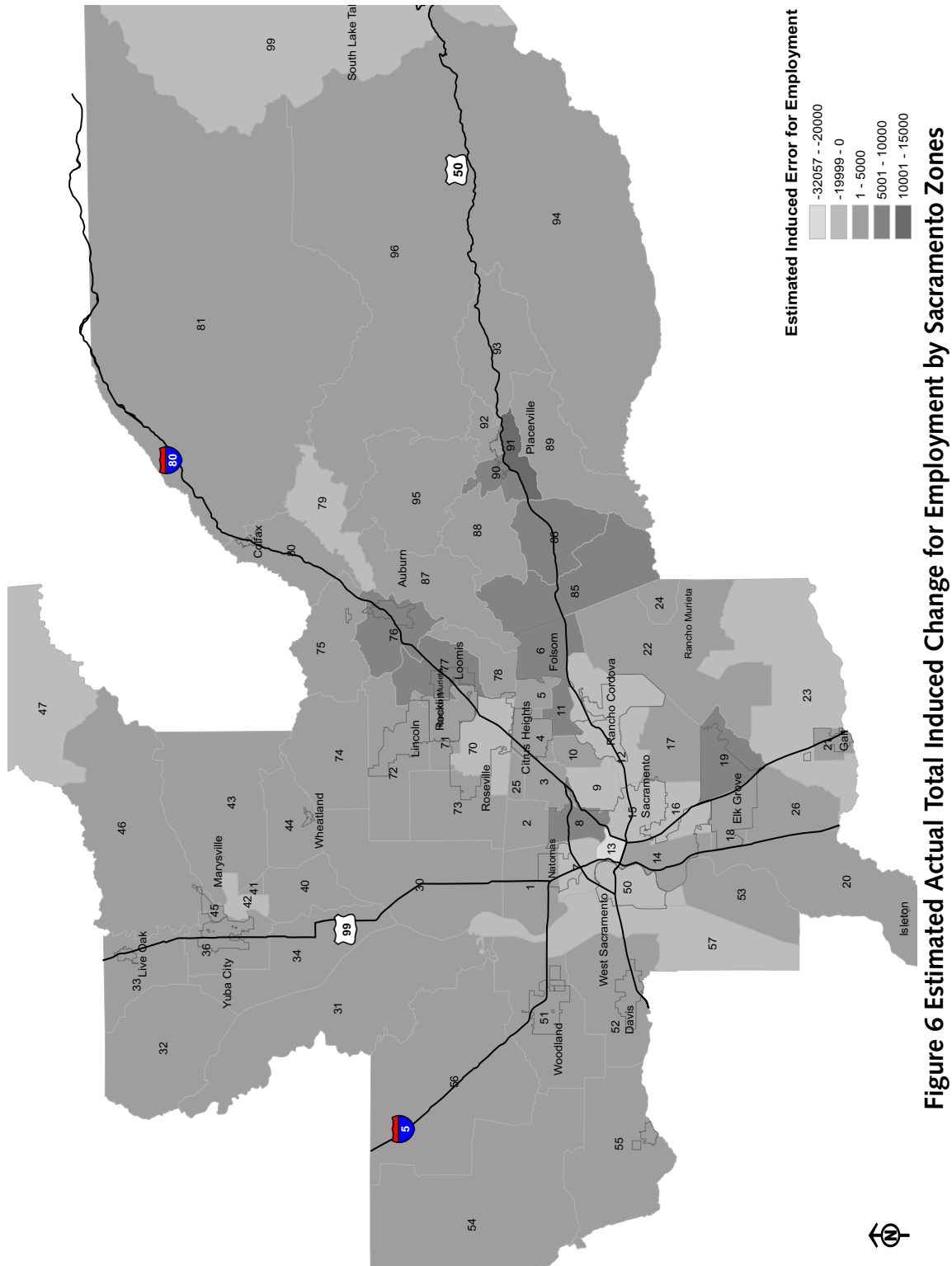
Figure 5 Zonal Distribution of Estimated Algebraic Induced Percent Change

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). Figure 6 and

Figure 7 depict the total estimated actual induced change for employment and households. This change (both modeled and estimated actual) tended to reduce employment in more established centers of the region, including the Sacramento central business district (CBD), West Sacramento, Rancho Cordova, and Roseville. Total employment loss was greatest for the Sacramento CBD (-32,057). Households were typically lost in the older regional suburbs in Arden Arcade, South Sacramento, Citrus Heights, and Orangevale. In general, employment and household activity increased in the outer ring of the region. The total increase in employment was 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 was most pronounced in the Franklin, Laguna, Antelope, Rocklin, and Lincoln zones. Thus, the relatively small negative percentage change (in Figure 4 and Figure 5) 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.

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 7. The share for model induced employment and nonresidential land was 21 and 32 percent, respectively, and for estimated induced change it was 27 and 30 percent respectively. The share for model induced households and residential land was 12 and 3 percent, respectively, and for estimated induced change it was 17 and 9 percent respectively. Table 7 also shows the number of zones that are greater than the absolute value of their model error (“significant” zones) by land category and the share of absolute model induced change in these zones relative to total regional population and land development. Sixty-five percent of zones were significant for employment and nonresidential land forecasts, and 31 and 10 percent of zones were significant for households and residential land forecasts, respectively. The share of significant model induced employment and nonresidential land was 14 and 21 percent, respectively; for households and residential land it was 3 and 1 percent, respectively. Relative to the regional total, the induced change in employment and nonresidential land can be considered relatively large for both total model induced and significant model induced.

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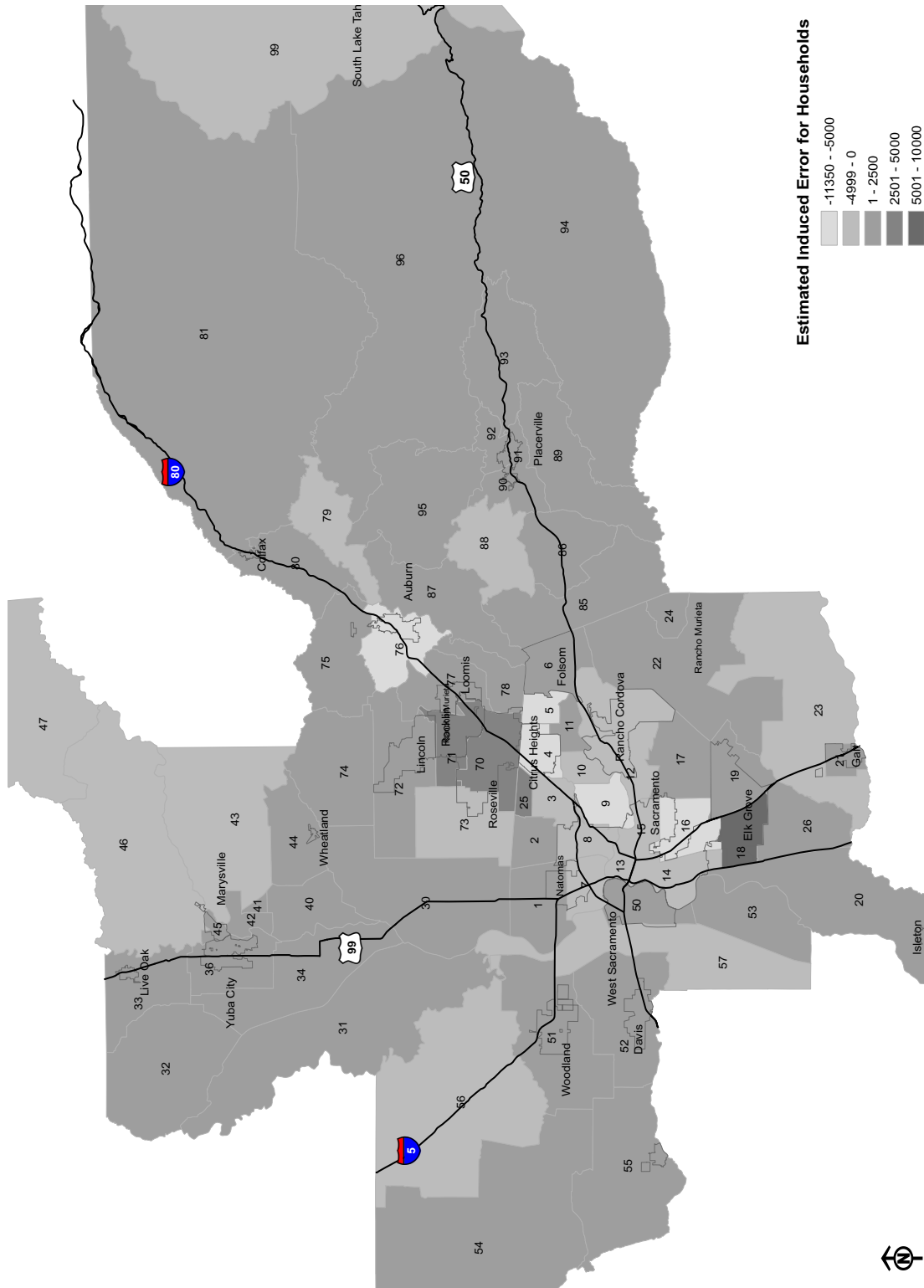


Figure 7 Estimated Actual Total Induced Change for Households by Sacramento Zones

model induced households and residential land was 12 and 3 percent, respectively, and for estimated induced change it was 17 and 9 percent, respectively. Table 7 also shows the number of zones that are greater than the absolute value of their model error (“significant” zones) by land category, and the share of absolute model induced change in these zones relative to total regional population and land development. Sixty-five percent of zones were significant for employment and nonresidential land forecasts, and 31 and 10 percent of zones were significant for households and residential land forecasts, respectively. The share of significant model induced employment and nonresidential land was 14 and 21 percent, respectively; for households and residential land it was 3 and 1 percent, respectively. Relative to the regional total, the induced change in employment and nonresidential land can be considered relatively large for both total model induced and significant model induced.

Table 7 Induced Land Use Change Relative to Regional Total

Absolute Percent	Model Induced^a	Estimated Induced^b	“Significant” Zones^c	“Significant” Model Induced^d
Employment	21 %	27 %	65 %	14 %
Nonresidential	32 %	30 %	65 %	21 %
Households	12 %	17 %	31 %	3 %
Residential	3 %	9 %	10 %	1 %

a. The absolute model induced change divided by simulated 2000

b. The absolute estimated induced change divided by observed 2000

c. The number of zones with model induced change greater than the absolute value of their model error

d. 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 8. The moderate roadway and highway expansion in the region over the 10-year period produced 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 (1 percent) and a larger increase in vehicle miles traveled (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 vehicle travel speed. However, the regional induced travel results for vehicle miles traveled, mean vehicle travel times, and

mean vehicle travel speed fall outside the absolute value of the error levels established in Table 8. As a result, the results may be considered significant with respect to model errors.

Table 8 Analysis of Induced Travel Results

Vehicle Travel	Model Induced	Estimated Induced
Vehicle Trips	-0.12 %	1.05 %
Vehicle Miles Travel	4.38 % *	4.46 % *
Mean Vehicle Travel Time	-9.44 % *	-7.62 % *
Mean Vehicle Travel Speed	15.52 % *	15.71 % *
Elasticity of VMT/Travel Time	-0.46 *	-0.58 *
Elasticity of VMT/Travel Speed	0.28 *	0.28 *
* Indicates that the absolute change is greater than the absolute value of the model error in Table 4		

CONCLUSION

State and regional governments across the United States are implementing more advanced land use and travel demand models to meet air quality conformity and environmental impact statement requirements. To guide applications of these models in policy studies better, this report describes an evaluation of model accuracy and induced demand representation over a 10-year period in the integrated land use and transportation model, the 2000 Sacramento MEPLAN model.

The accuracy evaluation in this study includes a simulation of year 2000 land use and travel that uses, as inputs, 1990 observed zonal land use data, observed regional growth estimates from 1990 to 2000, and observed changes in the regional transportation network from 1990 to 2000. This forecast is compared to observed 2000 land use and travel data to identify the magnitude of model error from errors in model functional forms and parameter specifications.

The induced demand analysis in this study includes a simulation of the year 2000 land use and travel in which the 1990 transportation network is held constant to the year 2000. The results are compared to the 2000 forecast and the 2000 transportation network to identify the model's representation of induced travel. The results are also compared to observed 2000 land use and travel data to estimate actual induced travel over the 10-year period.

The model accuracy evaluation indicates relatively high levels of percentage errors for zonal land use forecasts. Approximately 72 to 85 percent of the zones across the land use categories fall within plus/minus 100 percentage points. More zones have lower percentage errors for the employment and nonresidential land forecasts (56 and 34 percent, respectively, within plus/minus 50 percentage points) relative to the household and residential land forecasts (14 and 18 percent, respectively, within plus/minus 50 percentage points).

There are relatively modest percentage errors (less than 50 percent) for zones in the more established urban areas in the region, including the Sacramento CBD, Rancho Cordova, and Roseville. Larger errors are found in the outer areas of the region where the model tends to overestimate the location of households and employment. These errors may result from a developer model with limited sensitivity to prices set too low. It is also possible that the large zones in the outer regions tend to underestimate travel times because so much of their transportation system is abstracted into high-capacity centroid connectors, leading to

overestimates of household and employment location. The model's representation of land use trends over time may be improved by calibrating the model to two different points in time (for example, 2, 5, or 10 years apart).

The regional travel model error results indicate an overestimation of average vehicle travel times (14 percent) and an underestimation of average vehicle travel speeds (4 percent) and vehicle miles traveled (3 percent).

The induced demand analysis shows that moderate roadway capacity expansion over the 10-year period produces absolute percentage change in the zero to 25 percent range for 75 and 85 percent of zones for households and residential land, respectively, and in the 26 to 50 percent range for 30 and 35 percent of zones for employment and nonresidential land, respectively. Relative to the estimated actual induced travel, the model tends to overestimate the number of zones with smaller changes and underestimate the number of zones with larger changes (from 1 to 19 percent). The regional maps of total estimated actual induced change show employment losses in more established centers of the Sacramento region, household losses in the older regional suburbs, and employment and household activity increases in the outer ring. Sixty-five percent of zones could be considered significant (or greater than the absolute value of zonal model error by land category) for employment and nonresidential land forecasts; 31 and 10 percent of zones may be significant for households and residential land forecasts, respectively. The share of significant model induced employment and nonresidential land relative to the regional total is 14 and 21 percent, respectively; for households and residential land, it is 3 and 1 percent, respectively. The significant induced change in employment and nonresidential land can be considered large relative to the total regional population and the magnitude of the roadway capacity expansion projects over the 10-year time period.

The roadway expansion also reduces average vehicle travel time (7.6 percent) and increases average travel speed (15.7 percent) and vehicle miles traveled (4.5 percent). The elasticity of vehicle miles traveled with respect to travel time and speed are consistent with those reported in the empirical literature for shorter-term time horizons (-0.58 and 0.28, respectively). The regional induced travel results for vehicle miles traveled, mean vehicle travel times, and mean vehicle travel speed fall outside the absolute value of model error levels and thus may be considered significant.

The results of this case study have three key policy implications with respect to air quality conformity and environmental impact analyses:

1. To use the model in conformity analyses, the regional transportation plan emissions analysis should fall outside the 3 percent model error underestimate (for example, assuming VMT ranks with emissions) to demonstrate conformity.
2. For the analysis of travel effects of proposed highway investment projections in environmental impact statements, 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.
3. 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.

Validation tests can be used to improve the application of models in policy studies and in the policy process in general. Making uncertainty in a model explicit may alert the public and decision makers to potential problems and enable them to take steps now to avoid harmful future effects.

In the context of air quality conformity, if validation tests of a region's travel demand model indicate a downward bias in the model, then the region may want to ensure that it meets emissions budgets by an appropriate margin. This may involve more aggressive implementation of emission reduction measures (for example, technology-based strategies, land use measures, transit investment, and pricing policies) and reconsideration of new highway projects.

In the context of the National Environmental Policy Act (NEPA) process and, in particular, the analyses of proposed highway investments in environmental impact statements, 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.

Local interest groups have become increasingly suspicious of models used by metropolitan planning organizations in their conformity analyses and environmental impact statements. Such groups are concerned that models do not adequately represent induced travel and thus underestimate emissions effects of regional transportation plans that include new roadways or bias the analysis of alternatives in environmental impact statements in favor of roadway projects. Some are even concerned that underlying assumptions in the model are manipulated to make results meet emissions budgets or to make the proposed projects (generally roads) in environmental impact statements look beneficial.

As a result, there can be numerous technical debates and, ultimately, lawsuits over the adequacy of travel demand models that arise in both the air quality conformity and the NEPA processes. 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.

ENDNOTES

1. 40 CFR 93.122[b][1][iii]
2. "Travel Demand Model Peer Review," Wasatch Front Regional Council Summary of Proceedings, Salt Lake City, UT, May 18-19, 1999.
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15. Caroline J. Rodier, "A multi-objective analysis of regional transportation and land development policies," preprint for Transportation Research Board Annual Meeting, Washington, D.C., January 2005.
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18. Robert A. Johnston, Caroline J. Rodier, John E. Abraham, and John 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.
19. John E. Abraham and John D. Hunt, "Calibrating the MEPLAN model of Sacramento," Transportation Research Board Annual Meeting, Washington D.C., January 1998, paper 980649; John E. Abraham and John 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; John E. Abraham and John 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*; John E. Abraham and John 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*; and John E. Abraham, *Parameter Estimation in Urban Models: Theory and Application to a Land Use Transport Interaction Model of the Sacramento, California Region* (Ph.D. diss., University of Calgary, 2000).

ABBREVIATIONS AND ACRONYMS

ALE	Algebraic error
ALPE	Algebraic percent error
CAAA	Clean Air Act Amendment
CBD	Central business district
EALC	Estimated algebraic change
EALPC	Estimated algebraic percentage change
EAPC _i	Estimated absolute percentage change
MALC	Model algebraic change
MALE	Mean algebraic error
MALPC	Model algebraic percent change
MALPE	Mean algebraic percent error
MPO	Metropolitan planning organization
NEPA	National Environmental Policy Act
SACOG	Sacramento Area Council of Governments
TEA-21	1998 Transportation Equity Act for the 21 st Century
VMT	Vehicle miles traveled

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Caroline Rodier has a Ph.D. in Ecology from the University of California, Davis with emphasis in environmental policy analysis and transportation planning. She has more than 10 years experience applying land use, travel, and emissions models to evaluating the effects of a wide range of transportation and land use policies. Her most recent research in this area addresses key issues of modeling uncertainty in the context of environmental impact and air quality conformity processes. Dr. Rodier is currently a post-doctoral researcher at Partners for Advanced Transit and Highways at the University of California, Berkeley. In this position, she is conducting evaluation research of field operational tests that involve the application of advanced technologies to enhance access to transit, for example, smart parking and shared-use low-speed modes connected to Bay Area transit stations. She has authored more than 15 journal articles and more than 30 reports and proceedings articles.

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