CHAPTER ONE

INTRODUCTION

I. Presentation and Justification of Thesis Problem

The failures of models used in the analysis of travel and vehicle emissions effects of transportation plans and policies have been enumerated by many in the transportation profession over a period of almost three decades. Models can be insensitive to policy effects, and predictions are typically inaccurate. Despite these shortcomings, travel and emission modeling continues to be widely employed in transportation and environmental policy analysis. Within the last decade, travel and emission modeling has been made necessary by the Clean Air Act Amendments of 1990 (CAAA), the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and its successor the Transportation Equity Act for the 21st Century (TEA-21). Moreover, this legislation and resulting regulation demand a high degree of accuracy and precision from these models.

The systems that travel and emissions models simulate are complex and poorly understood. However, the social and environmental problems that these models address are critical. Models are the primary tools for understanding the behavior of complex systems, summarizing our knowledge, and allowing empirical evaluation. Models identify key causal relationships to predict the future, and thus offer us hope that steps can be taken now to avoid harmful future effects. Models can best advise by clearly delineating what is known and what is not. They can also be abused if their limitations are not understood, made explicit, and acknowledged.

This dissertation will attempt to provide methods for reasonable use by regional governments of travel and emission models that may contain multiple sources of error by regional governments. It will illustrate how methods of uncertainty analysis can be applied to regional travel and emissions models to gauge the effect of model error on the results of different policy alternatives. In addition, it will also answer key policy questions raised by the use of travel and emissions models to address current legislative and regulatory requirements. The dissertation will also demonstrate how uncertainty analyses can be used to identify the greatest sources of uncertainty in models and to instruct model improvement programs.

The Sacramento region will be used as the case study. This region is particularly interesting because it is an air quality nonattainment region and has a state-of-the-practice travel demand model.

Three areas of uncertainty in the region's travel and emission models will be examined: socioeconomic projections, the land use and transportation interaction, and induced travel. Methods of uncertainty analysis will be applied to the Sacramento region's travel and emission models to set confidence intervals on results and to determine whether the rank ordering of policy scenarios is altered when the effect of uncertainty is taken into account.

II. The Problem of Uncertainty in Travel and Vehicle Emissions Models

The limitations of models used in the analysis of travel and vehicle emissions effects of transportation policies have been enumerated by many in the transportation profession over a period of almost three decades. Models can be insensitive to policy effects, and predictions are typically inaccurate; it is not uncommon to find differences between predicted and actual values of 100%. The cause of these failures is generally attributed to the fact that models suffer from significant errors in their socioeconomic projections, land use projections, specification, measurement, and calibration.

Despite these shortcomings, travel and emission modeling continues to be widely employed without error analysis in transportation and environmental policy analysis. Within the last decade, travel and emissions modeling has been made legally necessary by the CAAA, ISTEA, and then TEA-21. Moreover, these statutes and the resulting regulations demand a high degree of accuracy and precision from these models. The conformity requirements of the CAAA assume the ability of travel models to estimate key travel inputs to emissions models accurately enough to forecast emissions to within a few percent. Some transportation professionals, perhaps optimistically, believe that current state-of-the-art methods can only forecast emissions with an accuracy of plus or minus 15 to 30 percent (Chatterjee et al., 1995). Furthermore, the transportation plans examined by regional governments across the U.S. typically differ from base case (or no-build scenarios) by less than one percent (Chatterjee et al., 1995). Not surprisingly, Martin Wachs (1995) reports that "methods of analysis in our field have become less important to policymaking, *less* influential in decision making than they were two decades ago."

In response to these problems, the U.S. Department of Transportation is currently funding the development of a new generation of activity-based microsimulation travel and modal emissions models (the $25 million TRANSIM program). For years, many in the transportation profession have called for a rethinking of the basic paradigm of travel demand modeling to incorporate advances in cognitive sciences, economics, and computation capacities (Harvey and Deakin, 1993). However, as Harvey and Deakin have stated, "If an understanding of the urban activity system is the goal, researchers and research sponsors must acknowledge the inherent complexity of the problems, which could be compared with research on global warming." The human and environmental systems that travel and emissions models are designed to predict are enormously complex, and scientific understanding of these systems is limited.

Compounding this already challenging modeling problem is the fact that empirical validation of travel and emissions models is extremely difficult, if not impossible. These models are required to make forecasts of the effects of transportation policies for 10- and 20-year time horizons. It is sometimes possible to calibrate models against historical data; however, this provides no assurance that past relationships will continue to hold in the future; many of the assumptions employed in the development of the models are simply not testable (Morgan and Henrion, 1990). Morgan and Henrion (1990) argue that when the system a model simulates is highly complex and poorly understood, "the need for empirical validation of any given model becomes secondary to a more general need for a coherent program of basic research."

However, the social and environmental problems that travel and emissions models are designed to address are critical and will likely worsen in the foreseeable future unless steps are taken to avoid their harmful effects. Many general overviews of transportation demand predict worldwide increases in vehicle miles traveled (VMT) and mobile emissions resulting from higher incomes, the shift to more energy-intensive modes (Schipper and Meyers, 1991), and vehicle growth rates that exceed population growth, particularly in developing countries (Walsh, 1991). In the U.S., lower out-of-pocket travel costs, decentralized basic employment (Wachs, 1981), and shelter costs that have risen in proportion to income have increased VMT, energy use, and mobile emissions.

These trends help explain the increased demands placed on travel and emissions models by U.S. legislation and regulations within the last decade. It is likely that despite their uncertainty there will always be a demand for the forecasts provided by large-scale models that address critical social and environmental problems. As evidence of such problems grows, so will the pressures placed on these analytical tools. Herbert Simon (1989) eloquently articulates the appeal of modeling:

> It is obvious why we are so fascinated by predictions of the future--whether achieved through horoscopes or otherwise. The future is our future, or at least the future of our children and their children. It bodes well or ill for us. Moreover, if we could forecast it, perhaps there are some actions we could take to alleviate its ill effects and enhance its favorable ones.

Models are the primary tools for understanding the behavior of large, complex systems; they summarize our current understanding of the system and allow this understanding to be subjected to critical empirical evaluation. In sum, models allow us to identify key causal relationships and to forecast the future and thus offer the hope that we can take steps now to avoid harmful effects in the future.

If large-scale models are primarily research tools and cannot be expected to accurately predict the future effects of policies, then the question becomes how can these models be responsibly used in policy analysis. Morgan and Henrion (1990) have asserted that the objective of large-scale models "should not be prediction but, rather, insight that can guide the development of heuristic policy strategies." Uncertain models should not be used to identify the best answer but rather to "help the decision maker to identify and explore possible alternatives as well as to choose among them" (Morgan and Henrion, 1990). As Rowen (1976) states:

> The contribution of policy analysis is essentially heuristic to provide a conceptual framework (or several) for relating means to ends, for thinking about ends, for identifying the existing technical alternatives, and for inventing new ones. In short, for many participants that analytic process will contribute to beliefs and facts and relationships and will help in the construction of value preferences. This reflects the view that preferences are generally built through experiences and through learning about facts, about relationships, and about consequences.

Others have argued that models can be used to "alert policy makers to the many scientific uncertainties, offer warnings against imposing 'one time solution strategies' and instead argue for 'adaptive' strategies that can respond appropriately as improved scientific understanding becomes available, and identify a number of scientific and policy questions that warrant careful further study" (Morgan and Henrion, 1990). Ayres (1984) has argued that "models may have more utility in conveying to decision makers the extreme sensitivity of outcomes to small changes in the choice of control variables when they are in certain critical ranges," and therefore "it seems imperative for modelers to give more attention to the range of uncertainty, with emphasis on uncertainty arising from decisions and policy choices not yet made."

The writings of these authors suggest a few guiding principles for the responsible use of uncertain models in policy analysis that will inevitably be used in policy analysis. Models should be used as heuristic tools. They should be used to inform but also to warn of the uncertainties and implied risks of decisions. Models can be abused if their limitations and uncertainties are not known, made explicit, and acknowledged.

What is needed, then, are practical methods for using uncertain models for policy analysis. Openshaw (1979) has complained about the dearth of advice about "how to use models based on inadequate theory and which use uncertain data to provide results in a form that may be useful in planning." He argues that "it is no use blaming models or data for being uncertain ... the problem is best solved by learning how to use models as uncertain tools, and this involves first being able to identify the levels of uncertainty in the results arising from errors in the models themselves and in the data they use." Furthermore, he asserts that identification of uncertainty will go far in discouraging naive interpretation of model results and help appease anti-modeling sentiments. Finally, he states that identification of uncertainty will not ultimately eliminate the use of models in planning, but rather may place them in a "more peripheral position" perhaps, the most appropriate place for highly uncertain models.

Unfortunately, uncertainty in models has traditionally been ignored not only in the transportation profession, but in policy analysis in general (Stopher and Meyberg, 1975; Hartgen, 1995; Morgan and Henrion, 1990). Morgan and Henrion (1990) lament that

> despite, or perhaps because of, the vast uncertainties inherent in most policy models, it is still not standard practice to treat uncertainties in an explicit probabilistic fashion, outside the relatively small fraternity of decision analysts.

David Hartgen (1995) calls for the acceleration of "healthy skepticism" of models used in the transportation profession. Furthermore, he asserts that "we will continue to need sensible modeling systems that allow realistic assessment of policy alternatives, within the constraints of risk and uncertainty" and that "effective model development and use should be based not on grandiose assertions of technical capability, but on realistic expectation about what models can and cannot do." Harvey and Deakin (1993) have also stated that there is a need to "assess the current precision and accuracy of data and models," "identify sources of uncertainty," and "develop approaches which could improve precision and accuracy and reduce uncertainty, including both model improvements and strategic planning (contingency) approaches."

To conclude, there are three key reasons why uncertainty analysis is critical. First, as Morgan and Henrion (1990) state, "policy analysts have a professional and ethical responsibility to present not just 'answers' but also a clear and explicit statement of the implications and limitations of their work." Second, uncertainty analysis helps separate facts from key value decisions that need to be made and places the consequences of risk with the decision-maker. Policy decisions that involve uncertain science require that value judgements be made about what counts as evidence; for example, in the U.S. evidence beyond a reasonable doubt is required to find someone guilty of a crime in the criminal justice system (Colglazier, 1991). Uncertainty analyses of travel and emission models will require that decision-makers determine the level of air quality risk that is acceptable to proceed with transportation projects. For example, is a 95%, 90%, or 80% chance of exceeding national air quality standards as a result of a transportation project acceptable? Third, the development of a model is inevitably an iterative process, and uncertainty analysis can be used to determine what areas of the model can most profitably be improved.

III. Description of Case

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

The Sacramento region is an air quality nonattainment region and has a state-of-the practice travel demand model. The region is also the site of a project, led by Professor Robert A. Johnston at the University of California at Davis, that compares three leading land use models (some integrated with travel models) calibrated on the same data sets and their results for a number of policy scenarios in the Sacramento region.

The modeling tools employed in this study will be the Sacramento Regional Travel Demand Model (SACMET96), an integrated and land use transportation model calibrated to the Sacramento region (the Sacramento MEPLAN model), and the California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) vehicle emissions model with the California Air Resources Board's EMFAC7F emissions factors.

IV. Organization and Integration of the Dissertation

This dissertation will consist of a number of studies, which together attempt to provide a set of methods for reasonable use of travel and emissions models. The application of these methods to the travel and emissions models of the Sacramento region will address key scientific questions raised by the use of travel and emissions models to address current legislative and regulatory requirements. Moreover, in combination these studies will illustrate how uncertainty analyses can be used to identify the greatest sources of uncertainty in models and to instruct model improvement programs. What follows are descriptions of the studies.

Chapter Two: Uncertain Socioeconomic Projections Used in Travel and Emissions Models: Could Plausible Errors Result in Air Quality Nonconformity?

In recent years, several regions (Charlotte, Atlanta, and New Jersey) have not met their air quality conformity tests, and it is not uncommon for regions to meet their tests by a very small margin. The Sacramento region is an example of just such a case; it just barely passed the conformity test for NOx emissions (by 0.04 tons out of 77.87 tons per day) for the year 1999. In this study, we conduct sensitivity analyses of plausible errors in population, employment, fuel price, and income projections using the Sacramento region's travel demand and emissions models for the transportation plan (2005 and 2015 time horizons). The results of the analyses indicate that plausible error ranges for household income and fuel prices are not a significant source of uncertainty with respect to the region's travel and emissions projections. However, plausible errors in population and employment projections (within approximately one standard deviation) may result in the region's transportation plan not meeting the conformity test for NOx in the year 2005 (i.e., an approximately 32% probability). This outcome is also possible in the year 2015 but less likely (within approximately two standard deviations or a 5% probability). These results have clear policy implications. First, regions like Sacramento that meet their conformity tests by a very small margin should rethink new highway investment and consider contingency transportation plans that incorporate more aggressive emissions reduction policies. Second, MPOs should conduct sensitivity analyses (similar to the ones in this study) as part of their conformity analysis to make explicit significant uncertainties in the methods and to identify the probability of their transportation plan not conforming. Third, the EPA should clarify the interpretation of “demonstrate” conformity of transportation plans; that is, specify the level of certainty that the EPA considers to be a sufficient demonstration of conformity.

Chapter Three: Air Quality Conformity Analysis of Transportation Plans: is it Important to Model the Land Use Effects?

In this study, we isolate the contribution that the representation of the land use and transportation interaction in an urban model makes to travel and vehicle emissions analyses of transportation scenarios in the Sacramento region over 25- and 50-year time horizons. One of the more theoretically consistent and practical operational urban models, MEPLAN, is used to simulate trend base case, high occupancy vehicle lanes (HOV), beltway freeways, and light rail and auto pricing scenarios. These transportation scenarios are simulated, first, with the full MEPLAN model to represent the land use and transportation interaction of the scenarios and, second, with the distribution of activities held constant from the future base case scenario so that the interaction is not represented. Vehicle emissions analyses are conducted with the California emissions model (DTIM2). The errors due to the failure to represent the land use changes for the light rail and pricing scenarios are small because of the comparatively limited range of the light rail network and auto pricing policies. However, the failure to represent the land use and transportation interaction from the HOV and Beltway scenarios significantly altered the magnitude of change for both travel and emissions results and the rank ordering of scenarios for emissions results. This error increases over time but is significant in the 25-year time horizon for both the HOV and the Beltway scenario. The HOV lane scenario was designed to include projects that are typical for a 20-year regional plan.

Chapter Four: Anatomy of Induced Travel Using an Integrated Land Use and Transportation Model in the Sacramento Region.

Recent research has provided persuasive evidence for induced travel. The principle has been acknowledged by the Transportation Research Board and by the Environmental Protection Agency. This has placed renewed attention on the ability of currently available analytical tools to capture the induced travel effects of proposed new highway projects. In this study, one of the more theoretically consistent and practical integrated land use and transportation models, MEPLAN, is used to evaluate the potential importance of land use and trip distribution induced travel effects in the Sacramento, California, region. The model is used to simulate a future base case scenario (low-build) and a beltway scenario for 25- and 50-year time horizons. First, the scenarios are simulated with the full Sacramento MEPLAN model set, and its implied elasticities of vehicle miles traveled with respect to lane miles are compared to the empirical literature. The findings indicate that these elasticities compare well. Second, three sensitivity tests are performed in an attempt to isolate the contribution of different induced travel effects. The scenarios are simulated holding constant the following effects from the future base case scenario to the beltway scenario: (1) land development, (2) land development and household and employment location, and (3) land development, household and employment location, and trip distribution. Each of these scenarios represents various methods of operating travel demand models to capture induced travel. Scenario (3) is equivalent to a travel demand model without feedback of assigned travel times to trip distribution; that is, only the mode choice and traffic assignment effects of induced travel are represented. Scenario (2) is equivalent to a travel demand model with feedback to trip distribution; that is, the trip distribution effects are added to scenario (3). Scenario (1) is equivalent to a travel demand model with feedback that is integrated with an activity allocation model; that is, the location of employment and population can vary with the scenario, but not acres of land developed. Elasticity is calculated for each sensitivity test, and the findings indicate that (3) does not account for a significant portion of induced travel, (2) accounts for approximately half, and (1) accounts for less than 20%. Third, the California vehicle emissions model is used to estimate the air quality effects of induced travel in the scenarios. Significant increases in VMT and emissions were found for the beltway scenarios run with the full MEPLAN model, and large errors were found when land use effects only were not represented and when land use and trip distribution effects were not represented.

Chapter Five: Heuristic Policy Analysis of Regional Land Use, Transit, and Travel Pricing Scenarios.

To address some of the uncertainties inherent in large-scale models, two very different urban models, an advanced travel demand model and an integrated land use and transportation model, are applied to evaluate land use, transit, and auto pricing policies in the Sacramento, California, region. The empirical and modeling literature is reviewed to identify effective land use, transit, and pricing policies and optimal combinations of those policies and to provide a comparative context for the results of the simulation. This study illustrates several advantages of this approach to addressing uncertainty in large-scale models. First, as Alonso (1968) asserts, the intersection of two uncertain models produces more robust results than one grand model. Second, the process of operationalizing policy sets exemplifies the theoretical and structural differences in the models. Third, a comparison of the results from multiple models illustrates the implications of the respective models' strengths and weaknesses and may provide some insights into heuristic policy strategies. Some of the key findings in this study are (1) land use and transit policies may reduce VMT and emissions by about 5% to 7%, and the addition of modest auto pricing policies may increase the reduction by about 4% to 6% compared to a future base case scenario for a 20-year time horizon; (2) development taxes and land subsidy policies may not be sufficient to generate effective transit-oriented land uses without strict growth controls elsewhere in the region; (3) parking pricing should not be imposed in areas served by light rail lines and in areas in which increased densities are promoted with land subsidy policies.

REFERENCES

Ayres, R. U. (1984). Limits and Possibilities of Large-Scale Long Range Societal Models. *Technology Forecasting and Social Change, 25, 297-308*.

Colglazier, E. W. (1991). Scientific Uncertainties, Public Policy, and Global Warming: How Sure is Sure Enough? *Policy Studies Journal, 19, 61-72*.

Hansen, Mark and Yuanlin Huang (1997). Road Supply and Traffic in California Urban Areas. *Transportation Research, A 31:3, 205-218*.

Hartgen, D. (1995). Virtual Models in Transportation. *Transportation Quarterly, 49: 4, 73-80*.

Harvey, G. and E. Deakin (1993). *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis*. National Association of Regional Councils.

Harvey, G. and E. Deakin (1995). *Description of the STEP Analysis Package*. Berkeley, CA.

Morgan G. and M. Henrion (1990). *Uncertainty.* Cambridge University Press, Cambridge, MA.

Noland, R. B. (1999). Relationships between Highway Capacity and Induced Vehicle Travel. Preprint for the 79th Annual Meeting of the Transportation Research Board. National Research Council, Washington, D.C., (January).

Openshaw, S. (1979). A methodology for using models for planning purposes. *Environment and Planning A, 11, 879-896.*

Rowen, H. S. (1976). Policy Analysis as Heuristic Aid: The Design of Means, Ends, and Institutions. In Tribe, L. & C. Schelling eds. *When Values Conflict*. Ballinger, Cambridge, MA.

Sacramento Area Council of Governments (1996). *1995 Regional Housing, Population, and Employment Projections*. Sacramento, CA.

Schipper, L. and S. Meyers (1991). Energy Use and Human Activity: Global Developments and Prospects. Transportation Research Board Conference on Transportation and Global Warming: Long-Range Options, Asilomar, CA.

Simon, H.A. (1989). Prediction and Prescription in System Modeling. *OR Forum*.

Stopher P. R. and A. H. Meyburg (1975). *Urban Transportation Modeling and Planning*. D.C. Heath and Company.

Transportation Research Board (1995). *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use, Special Report. 245.* National Research Council, Washington D.C.

Wachs, M. (1994). Keynote Address: Evolution and Objectives of the Travel Model Improvement Program. Travel Model Improvement Program Conference Proceedings. Prepared by Gordon A. Shunk and Patricia L. Bass. U.S. Department of Transportation and U.S. Environmental Protection Agency. (August 14-17).

Wachs, M. (1981). Social Trends and their Implications for Transportation Planning Methods. Resource paper for the Transportation Research Board Conference on Transportation Planning Methods, Warrentown, Virginia (November).

Walsh, M. P. (1991). Transportation Activity Trends and their Implication for Global Warming: the US in an International Context. Transportation Research Board Conference on Transportation and Global Climate Change: Long-Run Options, Asilomar, CA.

CHAPTER TWO

UNCERTAIN SOCIOECONOMIC PROJECTIONS USED IN TRAVEL AND EMISSIONS MODELS: COULD PLAUSIBLE ERRORS RESULT IN AIR QUALITY NONCONFORMITY?

by

Caroline J. Rodier and Robert A. Johnston

Abstract:

In recent years, several regions (Charlotte, Atlanta, and New Jersey) have not met their air quality conformity tests, and it is not uncommon for regions to meet their tests by a very small margin. The Sacramento region is an example of just such a case; it just barely passed the conformity test for NOx emissions (by 0.04 tons out of 77.87 tons per day) for the year 1999. In this study, we conduct sensitivity analyses of plausible errors in population, employment, fuel price, and income projections using the Sacramento region's travel demand and emissions models for the transportation plan (2005 and 2015 time horizons). The results of the analyses indicate that plausible error ranges for household income and fuel prices are not a significant source of uncertainty with respect to the region's travel and emissions projections. However, plausible errors in population and employment projections (within approximately one standard deviation) may result in the region's transportation plan not meeting the conformity test for NOx in the year 2005 (i.e., an approximately 32% probability). This outcome is also possible in the year 2015 but less likely (within approximately two standard deviations or a 5% probability). These

results have clear policy implications. First, regions like Sacramento that meet their conformity tests by a very small margin should rethink new highway investment and consider contingency transportation plans that incorporate more aggressive emissions reduction policies. Second, MPOs should conduct sensitivity analyses (similar to the ones in this study) as part of their conformity analysis to make explicit significant uncertainties in the methods and to identify the probability of their transportation plan not conforming. Third, the EPA should clarify the interpretation of "demonstrate" conformity of transportation plans; that is, specify the level of certainty that the EPA considers to be a sufficient demonstration of conformity.

I. Introduction

The limitations of models used in the analysis of travel and emissions effects of transportation policies and plans have been enumerated by many in the transportation profession over a period of almost three decades. Predictions are typically inaccurate; it is not uncommon to find differences between predicted and actual values of one hundred percent.

Although there are many sources of uncertainty in projections from travel and emissions models (including specification, measurement, and calibration error), socioeconomic projections are considered to be one of the greatest potential contributors. Travel demand models rely in large part on projections of population, employment, fuel prices, and incomes to generate future estimates of vehicle trips, vehicle miles traveled (VMT), and traffic volumes, which are then used in emissions models to make emissions projections.

The air quality problems that travel and emissions models are designed to address are critical. Approximately half of all Americans live in metropolitan areas that exceed at least one of the National Ambient Air Quality Standards (NAAQS) for carbon monoxide, ozone, or nitrogen dioxide (Ewing, 1997). Moreover, the new NAAQS 8-hour ozone standard adopted by the U.S. Environmental Protection Agency (EPA) in 1998 is expected to increase the proportion significantly. It appears that, even with new vehicle emission controls required by the Clean Air Act Amendments of 1990 (CAAA), NAAQS may not be met by the year 2010 because growth in VMT and vehicle trips and resulting emissions will have outstripped the reductions from these controls (Kessler and Schroeer 1995). However, the EPA has proposed new tailpipe standards (known as tier II) that could shift the 2010 date to 2030.

The CAAA and the resulting conformity regulations require that travel and emissions models be accurate enough to "demonstrate" that regional transportation plans and transportation improvement plans (RTPs and TIPs), which have a twenty year time horizon, conform to the emissions budgets set out in State Implementation Plans (SIPs). In addition, continuous monitoring is required to "demonstrate" attainment and maintenance of emissions budgets (58 FR 62188). If actual emissions exceed the emissions budget, then regions are held accountable, even if the analysis used the latest socioeconomic projections, travel modeling practices, and emission estimates. Nonconformity results in the automatic implementation of contingency measures and the loss of highway projects, but most importantly, the public's further exposure to harmful air pollutants. Three regions, Charlotte (North Carolina), Atlanta (Georgia), and New

Jersey, have already experienced significant highway project delays due to conformity lapses.

We conduct sensitivity analyses to represent the uncertainty in population, employment, fuel price, and income projections used in the region's travel model for its adopted transportation plans for the years 2005 and 2015, using the Sacramento region as the case study. Sensitivity analyses are employed to determine what level of error would be required in any uncertain variable to produce significant change in VMT and emissions and potentially cause the region's transportation plan to go out of conformity. As mentioned above, several regions have not met the conformity test in recent years, and it is not uncommon for regions to meet the test by a very small margin. The Sacramento region is an example of just such a case; it just barely passed the conformity test for NOx emissions (by 0.04 tons out of 77.87 tons per day) for the year 1999 (SACOG, 1999).

The broader significance of this research lies in the use of uncertainty analysis to make explicit significant potential errors in travel and emissions analyses that are conducted by MPOs for conformity analyses. Available models clearly are not able to simulate the travel and emissions effects of regional transportation plans to the degree of accuracy and precision required by the CAAA and the conformity regulations. The public and decision-makers may be made acutely aware of this fact when monitoring shows that a region has failed to meet its emissions budgets and penalties are imposed. The credibility of travel and emissions modeling can be maintained only by acknowledging and making explicit major areas of uncertainty in the analysis. Moreover, the public and decision-makers have a right to know what the chances are that a region will violate the NAAQS, given the implementation of a set of transportation projects and policies. Making uncertainty explicit gives them the opportunity to take steps now to hedge against this uncertainty, if they so desire. Uncertain travel and emission models can be used not only to inform, but also to warn of the great uncertainties and implied risks of decisions, thus separating facts from key value decisions that need to be made and placing the consequences of risk with the decision-maker.

II. Legislative and Regulatory Background

In recognition of the fact that unanticipated growth in vehicle travel had thwarted attainment of the NAAQS in the 1980s, Congress strengthened the conformity requirements of the CAAA of 1990. States are required to submit a revised SIP that demonstrates attainment of NAAQS by the attainment date, contains emissions control strategies, and sets out annual pollutant reduction levels (or emissions budgets). At the regional level, transportation plans (RTP and TIP) may be approved only if regional emissions analyses, commonly performed by MPOs, "demonstrate" that the plans are in conformity with the emissions budgets contained in the SIPs for each analysis or horizon year during and after the attainment year (58 FR 62188). Conformity determinations must use the most recent planning assumptions (including socioeconomic and travel projections) adopted by the MPO and the most recent emission estimates.

Most importantly, actual emissions in the region must not exceed the emissions budget. If they do, then contingency measures will automatically take effect. Transportation plans will not be in conformity, and highway projects may not be approved. In other words, regions must meet the emission budgets set out in the SIPs, even if the emissions analyses using the latest planning and emissions projections indicated that the transportation plan would conform.

Thus, the CAAA and the conformity regulations require that travel and emissions models be accurate enough to "demonstrate" conformity of transportation plans, which are prepared with a twenty-year time horizon, to emissions budgets (58 FR 62188). Accurate modeling is essential in order to avoid negative consequences of nonconformity, including the automatic implementation of contingency measures and the possible loss of federal funding for highway projects. Federal funds currently account for approximately 30% of total spending on roads.

III. Sensitivity Analyses of Socioeconomic Projections in Travel Demand Models

There are numerous sources of uncertainty in travel and emissions models. Alonso (1968) identifies two types of error, measurement error and specification error, and Stopher and Meyburg (1975) add calibration error to this list. Measurement error includes errors in estimating the values of variables (e.g., errors in reporting on travel surveys) and sampling errors (i.e., errors that arise from expanding a sample to the total population). Specification errors result from a failure to identify the true model or simplification of the true model. Calibration errors are obtained when variables that contain measurement errors are used to estimate model parameters. Harvey and Deakin (1995), however, assert that the uncertainty in socioeconomic projections used in travel and emissions models may be the greatest source of uncertainty in these models. Only a few studies have been conducted to gauge this uncertainty.

One study conducted a sensitivity analysis similar to the one proposed in this study. This analysis considered uncertainty in population growth as well as in fuel price and household income levels in the STEP models of the Los Angeles region (Cameron, 1991). The following example, provided by the study's modelers (Harvey and Deakin, 1995), underscores the importance of uncertain socioeconomic projections on model results:

> When significant congestion (and associated delay) begins to appear in a metropolitan highway system, the non-linearities of traffic flow make the delay increase roughly geometrically with population. Thus, in a region such as Los Angeles, already experiencing much highway congestion, a mistake in the assumed growth rate can have huge implications for the long-run impact of a policy such as congestion pricing. An analysis of LA congestion pricing in 2010 with a 2.5 percent growth rate versus a 1.5 percent growth rate (current "official" forecasts foresee a 2 percent growth rate) indicated that congestion pricing would be more than two times as effective at the higher rate (in hours of delay reduced), given the same infrastructure assumptions for both cases.

They chose plausible ranges for the variables and ran the model with extreme values to set confidence intervals on the results of a number of policy alternatives. They found that the estimated percentage change in total VMT ranged from 25% below to 15% above the original prediction. Thus, if the models projected that a policy would result in a 5% decrease in VMT, then error in the key input variables might raise the estimate of the absolute change in VMT to 5.75% or lower it to 3.75%.

Another study conducted a sensitivity analysis of higher than projected population estimates on emission trends for two metropolitan regions in California (San Diego and Fresno counties) that are serious ozone nonattainment areas (Thompson, Baker, and Wade, 1997). The high population projections were developed in consultation with the MPO for each region. In Fresno County, the growth rate is projected to be 3.0% per year, and the high growth simulations included growth rates of 3.5% and 4.0%. The regional travel model was run with the new projections. In the San Diego region, the growth rate is projected to be 1.5% annually. In this study, trip tables, rather than population growth rates, were adjusted to produce high and moderately high growth scenarios. They found that, even in the high growth scenarios for these regions, levels of CO, ROG, and NOx were below projected attainment year levels (2020) because of fuel and motor vehicle emissions control programs.

IV. Plausible Error Levels for Socioeconomic Projections

In this section, the literature is reviewed to identify plausible error ranges for the socioeconomic projections. In section V, the exact error levels used in the sensitivity analysis scenarios based on this review are specified.

A. Population

Population projections produced by various organizations for the state of California are reviewed by Hans Johnson (1999). These include the California Department of Finance (DOF), the United States Census Bureau (CB), the United States Bureau of Economic Analysis (BEA), the Anderson Forecast at UCLA, and the Center for Continuing Study of the California Economy (CCSCE). The CB produces a preferred and alternatives series, and the CCSCE produces high, medium, and low projections. The population projections made by these organizations for the years 2005 and 2015 are presented in Table 2.1.

Table 2.1. Population projections for California (in thousands)[1].

Year	Department of Finance (1998)	Census Bureau Preferred (1996)	Census Bureau Alternative (1996)	BEA (1995)	UCLA[2] (1998)	CCSCE Medium (1998)	CCSCE High (1998)	CCSCE Low (1998)
2005	37,372 (1.6%)[3]	34,441 (0.9%)	33,511 (0.6%)	36,657 (1.3%)	37,189 (1.4%)	37,800 (1.7%)	38,769 (2.0%)	36,831 (1.4%)
2015	42,371 (1.4%)	41,373 (1.3%)	36,838 (0.8%)	40,686 (1.2%)	43,756 (1.5%)	42,432 (3.2%)	45,439 (4.0%)	39,850 (2.4%)

[1] Note that all figures except those from UCLA were obtained from Johnson, 1999.
[2] UCLA projections are from UCLA, 1998.
[3] Annual growth rates.

A comparison of the population projections in Table 2.1 indicates large differences among them. In 2005, the difference between the lowest and highest projection is approximately 5 million, and the annual growth rates implied by these projections range from 0.6% to 2.0%. In 2015, the difference between the lowest and highest projection is approximately 9 million, and the annual growth rates range from 0.8% to 4.0%.

Hans Johnson (1999) explains the reasons for the different population projections by the various organizations:

> The differences in migration assumptions drive almost all of the differences among the various projections. Over the past 15 years, domestic migration between California and other states has fluctuated dramatically. It is possible that California is on the verge of a new demographic era, one in which the state no longer attracts more domestic migrants than it sends out. It is also possible that the state will return to its longtime demographic history of being a place that attracts more migrants from other states than it sends to those states. The lowest projections assume the former, while the highest projections assume the latter. The most recent evidence indicates that the large domestic migration losses of the early 1990s have ceased, although the state has not returned to the positive flows of domestic migrants that characterize the state's past.

The range of projections documented in Table 2.1 and the underlying reasons for the differences among projections suggest significant uncertainty with respect to future population growth in California.

In this study, we are interested in uncertainty in projections at the county-level for the Sacramento region. Projections at the county-level are known to be even more uncertain than at the state-level, because of more volatile growth rates and wider distributions of errors (Smith and Sincich, 1991). However, plausible high, medium, and low population projections at the county- or regional-level are not produced by any of the organizations described above or the local metropolitan transportation organization for the Sacramento region (SACOG). Table 2.2 documents the population projections at the county-level for the Sacramento region made by the DOF, CCSCE, and SACOG. A comparison of the annual growth rates shows that the variation among them is small, and thus plausible confidence intervals could not be set from the different projections.

Table 2.2. Summary of annual population growth rates to 2005 and 2015 for Sacramento region counties.

Sacramento Region Counties	SACOG (1995)	DOF (1996)	CCSCE (1998)	SACOG (1995)	DOF (1996)
	2005	2005	2005	2015	2015
El Dorado	2.9%	2.3%	2.3%	2.7%	2.2%
Placer	3.1%	3.1%	3.1%	2.9%	2.3%
Sacramento	1.6%	2.2%	2.2%	1.6%	1.7%
Yolo	2.6%	2.5%	2.5%	2.4%	2.2%
Sutter	2.4%	3.0%	3.0%	2.2%	3.1%
Yuba	2.0%	2.8%	2.8%	2.0%	2.3%
Region	2.0%	2.4%	2.4%	2.0%	2.0%

As a result, we sought reasonably available methods to construct confidence intervals on population projections at the county-level. One promising approach is the use of a comparison of past population projections with subsequent performance to set confidence intervals on future projections (Keyfiz, 1981; Pflaumer, 1988; Smith, 1987; Smith and Sincich, 1988; Stoto, 1983). Typically, the standard deviations of average projection error are used to set confidence intervals.

To apply the method, we collected past population projections of California counties made by the California Department of Finance (1962, 1967, 1971, 1977, 1983, 1986, and 1991), historical county census counts (California Department of Finance, 1998a), and intercensal county population estimates (California Department of Finance, 1998b; 1967). There are 59 counties in California. The jump-off projection years (i.e., the year of the population data used for the projection) for these projections are 1960, 1965, 1970, 1975, 1980, 1985, and 1990 (hereafter, projection years). Projections were available for at least 5-, 10-, 15-, and 20-year intervals (hereafter, projection intervals).

For each projection interval, the algebraic percentage point error (ALPE) of the projected population annual growth rate for each California county was calculated as

(1) $$ALPE_i = (P_i - A_i) * 100$$

where P is the projected population annual growth rate (from the California Department of Finance), A is the actual population annual growth rate (from census counts), and *i* is a California county. Next, the mean algebraic percentage error (MALPE) of the projected population annual growth rate for all California counties was calculated

(2) $$\text{MALPE} = (\sum \text{ALPE}_i)/n$$

where n is equal to the number of California counties. Finally, the standard deviation (s.d.) of the ALPE was calculated as

(3) $$\text{s.d. of ALPE}_i = \sqrt{[\Sigma(\text{ALPE}_i - \text{MALPE})^2/(n-1)]}.$$

The absolute value of the ALPE was calculated for equation (1) to (3) to obtain the absolute percentage point errors (APE), the mean absolute percentage point error (MAPE), and the standard deviation of the APE. The MALPE and MAPE and the standard deviations for the ALPE and APE by projection year and projection interval are presented in Tables 2.3 and 2.4.

Table 2.3. MALPE and MAPE of the projected annual percentage population growth rates for California counties.

	MALPE				MAPE			
	Projection Interval				Projection Interval			
Projection Year	5	10	15	20	5	10	15	20
1960	-0.28	0.62	0.30	0.13	0.92	1.09	1.08	1.05
1965	0.95	0.31	0.02	-0.06	1.15	0.90	0.82	0.74
1970	-0.75	-0.88	-0.74	-0.81	1.08	1.23	1.15	1.20
1975	-0.42	-0.37	-0.38	-0.38	0.69	0.71	0.73	0.73
1980	0.31	0.16	-0.03		0.66	0.69	0.67	
1985	-0.30	-1.20			0.67	1.30		
1990	0.66				0.79			
Average[1]	0.05	-0.24	-0.16	-0.28	0.84	0.98	0.89	0.92

[1] Average is of all data for an interval.

Table 2.4. Standard deviation of the ALPE and APE of the projected annual percentage population growth rates for California counties.

	S.D. OF THE ALPE				S.D. OF THE APE			
	Projection Interval				Projection Interval			
Projection Year	5	10	15	20	5	10	15	20
1960	1.30	1.13	1.29	1.30	0.96	0.68	0.75	0.77
1965	1.09	1.05	1.05	0.97	0.87	0.61	0.64	0.64
1970	1.13	1.28	1.19	1.23	0.81	0.93	0.79	0.85
1975	0.76	0.79	0.80	0.84	0.52	0.50	0.49	0.55
1980	1.01	1.02	0.96		0.82	0.76	0.69	
1985	0.88	1.02			0.65	0.89		
1990	0.73				0.58			
Average [1]	1.14	1.23	1.12	1.14	0.77	0.78	0.70	0.73

[1] Average is of all data for an interval.

In the calculation of the mean errors and the standard deviation of the percentage point errors, we controlled for counties with very small population size and extreme growth rates. Based on our analysis of the data, we eliminated counties with outlying population size and growth rates. These outliers included counties with populations less than 1000 and with annual growth rates less than or equal to –0.01% and greater than or equal to 4.6%. Estimation errors commonly increase as population size decreases (e.g., Kitigawa and Spencer, 1981; Smith, 1986; Smith and Sincich, 1988; Smith and Cody, 1994; U.S. Bureau of the Census 1985). There have also been reports that growth rates have a U-shaped effect on population estimates (U.S. Bureau of the Census, 1985) and projections (Smith, 1987); that is, errors increase in very rapidly growing or declining areas.

The range of the standard deviation for the algebraic percentage point error of projected county annual growth rates in Table 2.4 is 0.73% to 1.30% and the average standard deviation is approximately 1.0% for all projection intervals. Based this analysis, we believe that a plausible standard deviation for the errors is ± 1.0% and a plausible error range is two standard deviations or ± 2.0%.

Note that historical projection data from SACOG could not be used because of limited records and changes in the region's boundaries over time. However, the SACOG projections are strongly influenced by DOF projections.

B. Employment

The only source of employment estimates for 2005 and 2015 at the regional or county-level besides SACOG (1995) was DRI (1994). DRI provides high and low estimates of growth rates; however, the variation in this range was so small that a sensitivity analysis using these numbers would be pointless. Moreover, SACOG in its projection method starts with population estimates and then applies a jobs-housing ratio for sub-areas to make employment projections. (Note that population is converted to housing units in the model with a housing-population ratio by sub-area.) Thus, with the SACOG method employment errors should co-vary with population estimates. As a result, we decided to vary population and employment jointly by applying error rates for population.

C. Household Income

CCSCE is the only organization that projects household income at the regional and county-levels for California. (Note that the SACOG travel model uses household income rather than per capita income.) CCSCE (1997) also makes high, medium, and low household income projections. In Table 2.5, we present the CCSCE (1997) projections of household income in 1996 dollars for the Sacramento regional counties for the year 2005. The difference between the high and low projections of average household income for the Sacramento region is $7,000, which is reasonably significant.

Table 2.5. CCSCE (1997) projections of average household income in 1996 dollars.

	1990	1996	1996-2005		
			Low	Moderate	High
El Dorado	60,834	67,023	72,538	75,569	76,690
Placer	66,347	75,469	83,294	86,774	91,506
Sacramento	58,482	62,070	72,628	75,663	79,789
Yolo	58,676	63,460	71,800	74,396	78,879
Sutter	53,970	58,385	63,715	66,377	69,997
Yuba	42,940	46,327	51,120	53,256	56,160

CCSCE (1997) states that "there is a considerable uncertainty about the rates at which real income will grow." This uncertainty is due largely to variations in productivity growth and real wage growth assumptions. In addition, income trends may diverge from productivity trends because of demographic factors, for example, gains in labor participation rates and larger numbers of seniors and children.

CCSCE describes the recent history of the trends in average household incomes:

> During the 1980s real average household income increased by 1.5% per year. The primary force pushing household income up was increases in the number of workers per family – not increase in real wages. The average number of workers rose because 1) more women entered the labor force and 2) the number of adults per household rose in Hispanic and Asian households. These demographic trends continued during the early 1990s. As a result average household income, adjusted for inflation, grew slightly between 1990 and 1996 despite a drop in real wages.

CCSE predicts that:

> Average household income should grow by approximately 1.3% per year in the decade ahead. The key determinant of future growth will be productivity gains.

Demographic factors will be neutral with a continued increase in female labor force participation being offset by an anticipated "unbundling" of some immigrant households as real wages grow.

D. Fuel Price

In a special report of *Scientific American* called "Preventing the next Oil Crunch," Colin Campbell and Jean Laherrere (1998) conclude that by 2010 the abundant supply of conventional oil that has kept oil prices low will end and that this supply will then decline permanently. However, other supplies (e.g. new wells beneath the ocean) and/or alternatives may become available (e.g. conversion of natural gas and oil sands to liquid fuels). Because the response to reduced conventional oil supplies is unknown, there is considerable uncertainty surrounding future fuel prices.

The California Energy Commissions (CEC, 1998) and the Energy Information Administration (EIA, 1998) both produce high, medium, and low estimates of future fuel prices. The projected percentage change in fuel prices from 1990 to 2005 and 2015 are presented in Table 2.6. The greatest percentage point difference between the 1990 and 2005 scenarios is 15.6% and the 1990 and 2015 scenarios is 33.1%.

Table 2.6. Percentage change in fuel price from 1990 projected by the CEC (1998) and the EIA (1998).

Year	CEC Low	CEC Best	CEC High	EIA Low	EIA Best	EIA High
2005[1]	-6.66	0.00	0.00	-7.11	1.93	8.78
2015	-15.47	0.00	0.00	-11.77	3.52	17.66

[1]Note that 2005 figures for the EIA were interpolated from annual growth estimates from 1990 to 2010.

For the CEC projections, the prices for the high and mid price scenarios are not projected to increase over time because these scenarios include assumptions of a flat rate of real oil price growth, constant real excise taxes, constant mark-up, and no real changes to fuel regulations from environmental regulations. The base year prices are only very slightly higher for the high and mid price scenarios than the low price scenarios.

V. Description of the Travel Demand and Emissions Models

SACMET96 was developed with a 1991 travel behavior survey and makes use of over one thousand travel analysis zones (DKS & Associates, 1994). Some of the key features of this model include: (1) full model feedback of assigned travel impedances to the trip distribution step; (2) auto ownership and trip generation steps with accessibility variables; (3) a joint destination and mode choice model for work trips; (4) a mode choice model with separate walk and bike modes, walk and drive transit access modes, and two carpool modes; (5) land use, travel time and monetary costs, and household attribute variables included in the mode choice models; (6) all mode choice equations in logit form; and (7) a trip assignment step that assigns separate A.M. and P.M. peak (both 3 hour and 1 hour peak) and off-peak periods. SACMET meets the Environmental Protection Agency's modeling requirements for nonattainment regions.

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) emissions model and the California Air Resources Board's EMFAC7F1.1 emissions factors are used in the emissions analysis. The outputs from the travel demand model used in the emissions analysis included the results of assignment for each trip purpose by each time period (A.M. peak, P.M. peak, and off-peak). SACOG provides regional coldstart and hotstart coefficients for each hour in a twenty-four hour summer period.

VI. Scenarios

The base scenario in this analysis is the 1996 Metropolitan Transportation Plan (MTP) for 2005 and 2015. This plan includes new highway, roadway, and transit projects. The alternative scenarios simulated for the sensitivity analyses represent plausible errors in population and employment projections, household income, and fuel price and are presented in Table 2.7.

Table 2.7. Summary of scenarios for sensitivity analyses.

Population & Employment		Household Income		Fuel Price	
2005	2015	2005	2015	2005	2015
-2.0%	-2.0%	0.0%	0.0%	-7.11%	-15.5%
-1.5%	-1.5%	10.0%	10.0%	-3.50%	-7.5%
-1.0%	-1.0%	20.0%	20.0%	0.0%	0.0%
-0.5%	-0.5%	30.0%	30.0%	3.50%	7.5%
0.0%	0.0%	32.8%	40.0%	8.78%	17.7%
0.5%	0.5%		50.0%		
1.0%	1.0%		69.9%		
1.5%	1.5%				
2.0%	2.0%				

Note that one variable is varied at a time. Note also that the figures above for population and employment are percentage points and for household income and fuel price are percentage change.

Based on our analysis in section III, we identify ±2.0% as plausible error ranges for the 2005 and 2015 annual population and employment growth projections in the SACMET96 model. The error levels were applied to county population and employment projections used in the model in each time horizon. In section III-A, we identify a plausible standard deviation of ± 1.0% for the error on annual population growth rates for California counties. If the distribution of errors is normal, then there is about a 68% chance that the true value for the error will fall within one standard deviation (± 1.0%) and about a 95% chance that it will fall within two standard deviations (± 2.0%). Stem-and-leaf plots indicate a normal curve for the algebraic errors for all time intervals. The hypothesis of normality for the Lilliefors test could not be rejected at the 0.05 level of significance for three of the four time intervals.

Household income is assumed to remain constant for the Sacramento region in the SACMET96 model. However, even the low household income projections from CCSCE project an increase in real income growth. This is consistent with DOF predictions of an increase in real per capita income (1997). The percentage change in household income from 1990 to 2005 for the Sacramento region was calculated from the CCSCE figures presented in Table 2.5. CCSCE does not make projections to 2015. As a result, we calculated annual percentage change in household income growth from 1990 to 2005 for the low, moderate, and high scenarios. These figures were then used to estimate percentage change in total household income growth from 1990 to 2015. For the year 2005, we estimate a low percentage change of 21.6%, a moderate percentage change of 26.6%, and a high percentage change of 32.8%. For the year 2015, we estimate a low percentage change of 39.0%, a moderate percentage change of 52.0%, and a high percentage change of 68.9%. We then applied a growth range from 0% to 32.8% for the year 2005 and growth range from 0% to 68.9% for the year 2015.

Fuel prices are also assumed to remain constant in the SACMET96 model for the future time horizons. This assumption is consistent with the CEC (1998) projections but is somewhat low compared to the EIA (1998) projections (see Table 2.6). We used the lowest and highest figures for the horizon year from Table 2.6 as plausible ranges of change in fuel prices. Thus, we applied a range of –7.1% to 8.8% in 2005 and a range of –15.47% to 17.7% in 2015.

VII. Results

The results of the sensitivity analyses for the year 2005 MTP are presented in Table 2.8 and Figure 2.1, and the results of the sensitivity analyses for the year 2015 MTP are presented in Table 2.10 and Figure 2.2.

The results indicate that error in the projections of household income and fuel prices is not a significant source of uncertainty in SACMET96's projection of future travel and emissions. The model appears to be relatively insensitive to these variables. Household income and fuel price variables are represented in the mode choice model for all trips but only in the trip distribution model for work trips. For 2005, the range of percentage change resulting from plausible errors in household income is 0.0% to 0.3% for VMT and 0.0% to 0.3% for emissions and in fuel prices is -0.1% to 0.1% for VMT and -0.2% to 0.1% for emissions. For 2015, the range of percentage change resulting from plausible errors in household income is 0.0% to 0.6% for VMT and 0.0% to 0.6% for emissions, and in fuel prices the range of change is -0.2% to 0.2% for VMT and -0.3% to 0.1% for emissions.

In contrast, plausible error levels for population and employment projections generate relatively large changes in travel and emissions. For 2005, the range of percentage change resulting from plausible errors in population and employment projections is –12.0% to 13.6% for VMT and –15.3% to 17.3% for emissions. For 2015, the range of percentage change resulting from plausible errors in population and employment projections is -21.8% to 28.5% for VMT and –28.4% to 43.7 for emissions.

To gauge the significance of the results of the sensitivity analyses, we compare the margin of error in the MTP emissions projections due to plausible errors in socioeconomic projections (presented above) to the margin within which the MTP conforms to its emissions budget. Again, the margin of error in the sensitivity analyses is represented as percentage change from the sensitivity scenario to the MTP projections. The margin of error in the conformity analyses is represented as percentage change from the SIP budget to the MTP projections (for ROG, NOx, and CO). Because there are no SIP budgets for PM_{10}, for that pollutant the percentage change is from the no plan to the plan (for Sacramento County only). In Table 2.9, we present the margin of error for the 1996 and 1999 conformity analyses for the year 2005. In Table 2.11, we present the margin of error for the 1996 and 1999 conformity analyses for the year 2015.

Table 2.8. Percentage change results of sensitivity analyses from the 2005 MTP.

	VEHICLE TRAVEL			VEHICLE EMISSIONS (TONS)			
	TRIPS	VMT	VHD	TOG	CO	NOx	PM
Population & Employment[1]							
-2.0%	-16.7%	-12.0%	-39.2%	-15.3%	-15.0%	-11.0%	-13.2%
-1.5%	-12.8%	-9.1%	-30.3%	-11.8%	-11.5%	-8.4%	-10.2%
-1.0%	-8.7%	-6.2%	-21.4%	-8.2%	-7.9%	-5.7%	-7.0%
-0.5%	-4.4%	-3.1%	-11.9%	-4.1%	-4.0%	-2.9%	-3.6%
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5%	4.6%	3.2%	12.7%	4.4%	4.2%	2.9%	3.9%
1.0%	9.4%	6.6%	29.2%	9.2%	8.6%	6.0%	7.9%
1.5%	14.4%	10.0%	47.7%	14.4%	13.2%	9.1%	12.3%
2.0%	19.7%	13.6%	68.8%	20.1%	18.1%	12.4%	17.3%
Household Income[2]							
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10.0%	0.0%	0.1%	0.5%	0.0%	0.0%	0.0%	0.0%
20.0%	0.0%	0.2%	1.1%	0.1%	0.1%	0.1%	0.1%
30.0%	0.1%	0.3%	1.4%	0.2%	0.1%	0.2%	0.3%
32.8%	0.1%	0.3%	1.8%	0.2%	0.1%	0.2%	0.3%
Fuel Price[3]							
-7.11%	0.0%	0.1%	0.5%	0.1%	0.0%	0.0%	0.1%
-3.50%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.50%	0.0%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%
8.78%	0.0%	-0.1%	-0.4%	-0.1%	-0.1%	-0.1%	-0.2%

[1] Error levels for projected annual population growth rates for California Counties within 2 standard deviations.
[2] Error levels for household incomes for counties in the Sacramento region from CCSCE, 1997.
[3] Error levels for fuel price from the CEC, 1998 and EIA, 1998.

Table 2.9. Year 2005 absolute percentage change[1] in emissions for the 1996 and 1999 conformity analysis (SACOG, 1998; 1999).

	1996 MTP Conformity	1999 MTP Conformity
ROG	26.2%	25.3%
NOx	6.9%	2.8%
CO	256.5%	262.2%
PM_{10}[2]	1.5%	3.6%

[1] Absolute percentage change from the SIP Budget to the MTP for ROG, NOx, and CO and absolute percentage change from the no plan to the plan for PM10 (because no SIP budget exists for PM10). These figures represent by what percentage the MTP was lower than the SIP Budget.

[2] PM_{10} figures are for Sacramento County only.

Figure 2.1. 2005 MTP: Percentage change in VMT and emissions for errors in population and employment growth projections

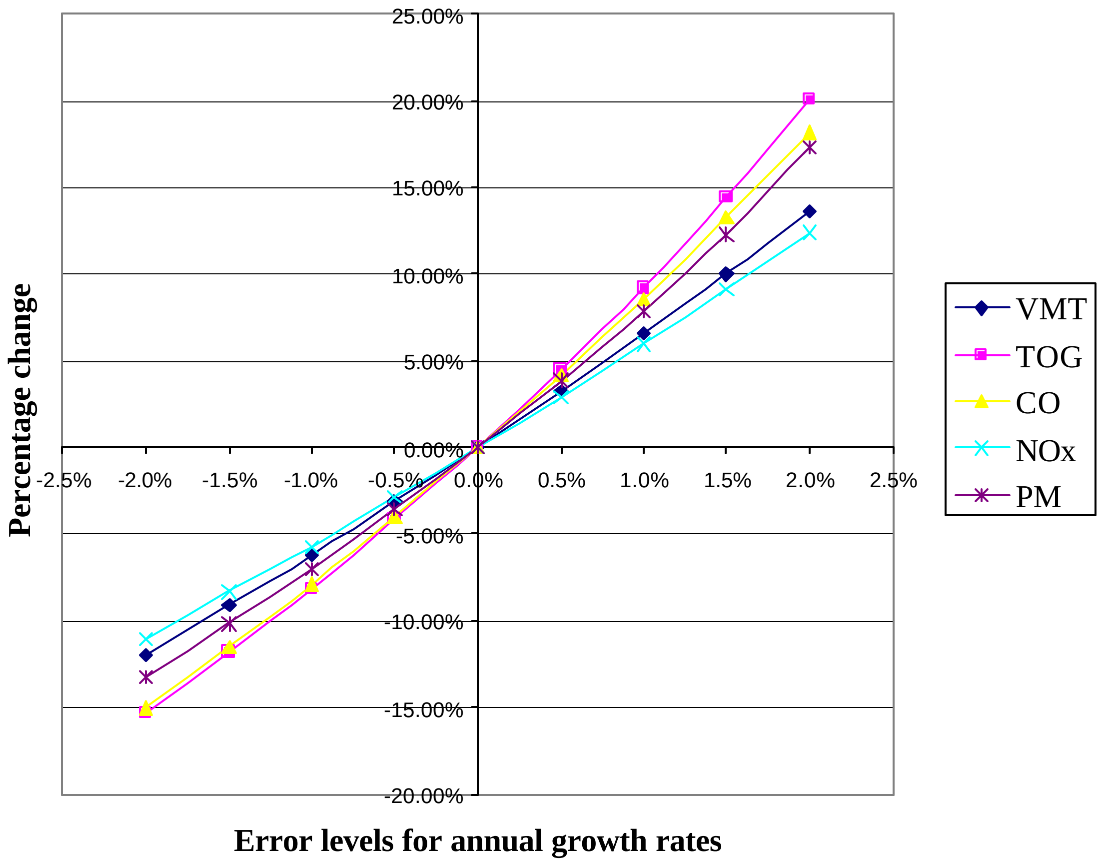


Table 2.10. Percentage change results of sensitivity analyses from the 2015 MTP.

	VEHICLE TRAVEL			VEHICLE EMISSIONS (TONS)			
	TRIPS	VMT	VHD	TOG	CO	NOx	PM
Population & Employment[1]							
-2.0%	-30.2%	-21.8%	-58.9%	-28.4%	-26.9%	-20.0%	-24.0%
-1.5%	-16.7%	-18.4%	-43.1%	-23.0%	-21.4%	-14.9%	-18.2%
-1.0%	-16.4%	-11.7%	-38.7%	-15.8%	-14.8%	-10.7%	-13.1%
-0.5%	-8.6%	-6.1%	-21.0%	-8.4%	-7.8%	-5.6%	-6.8%
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.5%	9.3%	6.5%	30.2%	10.2%	8.6%	7.0%	11.7%
1.0%	19.5%	13.3%	66.8%	21.9%	18.4%	13.6%	22.3%
1.5%	30.5%	20.7%	118.3%	30.8%	28.1%	18.9%	24.0%
2.0%	42.5%	28.5%	184.6%	43.7%	39.6%	26.2%	33.6%
Household Income[2]							
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
20.0%	0.0%	0.2%	0.5%	0.1%	0.1%	0.1%	0.1%
30.0%	0.1%	0.2%	0.6%	0.2%	0.1%	0.2%	0.2%
40.0%	0.1%	0.4%	1.3%	0.2%	0.2%	0.2%	0.3%
50.0%	0.1%	0.5%	1.8%	0.3%	0.2%	0.3%	0.4%
69.9%	0.1%	0.6%	2.9%	0.4%	0.3%	0.4%	0.6%
Fuel Price[3]							
-15.5%	0.0%	0.2%	0.7%	0.1%	0.1%	0.1%	0.1%
-7.5%	0.0%	0.1%	0.5%	0.0%	0.0%	0.0%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.5%	0.0%	-0.1%	-0.3%	-0.1%	-0.1%	-0.1%	-0.1%
17.7%	0.0%	-0.2%	-1.4%	-0.2%	-0.1%	-0.1%	-0.3%

[1] Error levels for projected annual population growth rates for California Counties within 2 standard deviations.
[2] Error levels for household incomes for counties in the Sacramento region from CCSCE, 1997.
[3] Error levels for fuel price from the CEC, 1998 and EIA, 1998.

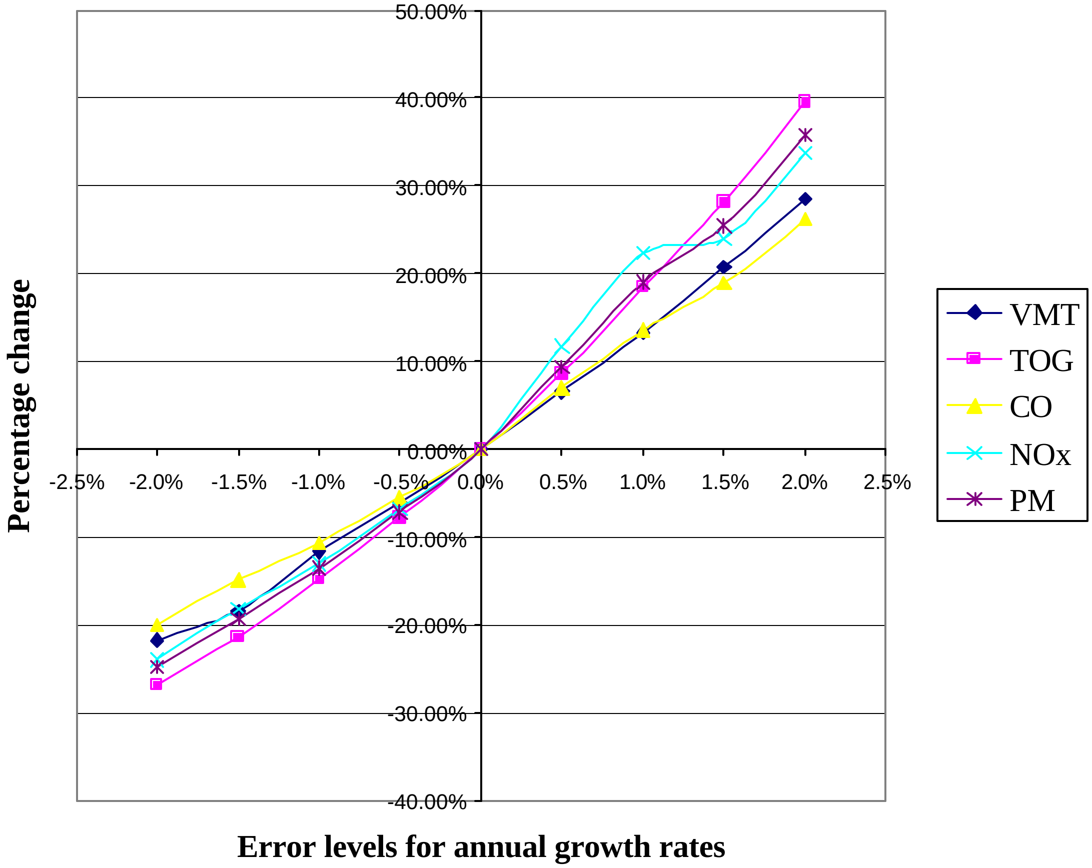
Table 2.11. Year 2015 absolute percentage change[1] in emissions for the 1996 and 1999 conformity analysis (SACOG, 1998; 1999).

	1996 MTP Conformity	1999 MTP Conformity
ROG	99.5%	86.0%
NOx	27.3%	17.5%
CO	386.8%	377.2%
PM_{10}[2]	6.1%	6.0%

[1] Absolute percentage change from the SIP Budget to the MTP for ROG, NOx, and CO and absolute percentage change from the no plan to the plan for PM10 (because no SIP budgets exists for PM10). These figures represent by what percentage the MTP was lower than the SIP Budget.

[2] PM_{10} figures are for Sacramento County only.

Figure 2.2. 2015 MTP: Percentage change in VMT and emissions for errors in population and employment growth projections



In order to evaluate the comparison of the margin of errors for the sensitivity analyses to the margin of error for the conformity analyses, we provide details of the respective projection methods. Our analysis used the same travel demand model, emissions model and factors, and transportation network as the 1996 MTP conformity analysis. The 1999 MTP conformity analysis used an updated version of the SACMET96 model, the same emissions model and factors, and a somewhat revised transportation network. The conformity analyses for both years includes emissions projections from northern Solano County and various approved adjustments factors that are applied off-model to reduce total emissions; we, however, did not incorporate these adjustments in our analysis. In addition, a conversion factor is applied to TOG (total organic gases) to convert it to ROG (reactive organic gases), but we did not convert TOG to ROG because it would not alter percentage change results (i.e., TOG is multiplied by set factor). In sum, the comparison to the 1999 conformity analysis is only approximate.

Before we present the results of the comparison, we restate the confidence interval for population and employment projections and its interpretation. We identified ± 1.0% as a plausible confidence interval (one standard deviation) for population and employment projections for counties in the region. If the distribution of errors is normal, then there is a 68% chance that the true value of the error will fall within this confidence interval and a 95% chance that it will fall within two standard deviations (± 2.0%). As described above, we did find evidence that the algebraic errors were distributed normally for the time intervals.

We now compare results of the sensitivity analyses to the results of the conformity analyses. For the year 2005, the results of the 1996 conformity analysis indicate that the percentage change for NOx is just above the +1.0% error level, and the 1999 conformity analysis indicates that percentage change for NOx falls below the 0.5% and 1.0% levels (but is closer to the 0.5% level). See Tables 2.8 and 2.9. If population grows by 1% faster per year than assumed in the baseline projection (i.e., an error of +1.0%), then NOx emissions would be 6.0% higher than baseline NOx emissions. This is just under the 6.9% margin by which the region's transportation plan passed its NOx conformity test. However, if the population grows by 1.5% faster per year than assumed in the baseline projection (i.e., an error of +1.5%), then NOx emissions would be 9.1% higher than baseline NOx emissions. This is over the 6.9% margin by which the region's transportation plan passed its NOx conformity test. In both conformity analyses for the year 2005, ROG and CO would fall outside the specified error range (two standard deviations).

For the year 2015, the results of the 1996 conformity analysis indicates that percentage change for NOx is just outside the 2.0% error level, and the 1999 conformity analysis indicates that the percentage change in NOx is between the 1.0% and 1.5% error level (but closer to the 1.5% level). See Tables 2.10 and 2.11. If population grows by 2% faster per year than assumed in the baseline projection (i.e., an error of +2.0%), then NOx emissions would be 26.2% higher than baseline NOx emissions. This is just under the 27.3% margin by which the region's transportation plan passed its NOx conformity test.

We can't compare PM_{10} because our numbers are for the region and the conformity numbers are for Sacramento County only. However, the percentage change (or margin by which the plan meets the conformity test) is quite small, and thus small errors in population growth rates could result in failure to meet the conformity test.

VIII. Conclusions

In this study, we conducted sensitivity analyses of plausible errors in population, employment, fuel price, and income projections using the Sacramento region's travel demand and emissions models for the transportation plan (2005 and 2015 time horizons). The results of this analysis indicate that plausible error ranges for household income and fuel prices are not a significant source of uncertainty with respect to the region's travel and emissions projections. However, plausible errors in population and employment projections (within approximately one standard deviation) may result in the region's transportation plan not meeting the conformity test for NOx in the year 2005. In other words, there is an approximately 32% chance that the region's transportation plan will not meet the conformity test for NOx in the year 2005. This outcome is also possible in the year 2015 but less likely (within approximately two standard deviations or a 5% chance).

These results have clear policy implications. First, regions like Sacramento that meet their conformity tests by a very small margin should rethink new highway investment and consider contingency transportation plans that incorporate more aggressive emissions reduction policies (e.g., land use measures or pricing policies). Second, MPOs should conduct sensitivity analyses (similar to the ones in this study) as part of their conformity analysis to make explicit significant uncertainties in the methods and to identify the probability of their transportation plan not conforming. Third, the

EPA should clarify the interpretation of “demonstrate” conformity of transportation plans; that is, specify the level of certainty that the EPA considers to be a sufficient demonstration of conformity.

REFERENCES

DRI/McGraw-Hill (1994). *A Study to Develop Statewide and County-Level Economic Projections. Volume I: California Country Economic Forecasts*. Contract No. 92-326. Prepared by Jay Kloepfer. California Air Resources Board, Sacramento, CA (August).

California Department of Finance (1962). *Preliminary Projections of California Areas and Counties to 1975*. Financial and Population Research Unit, Sacramento, CA.

____ (1967). *Preliminary Projections of California Areas and Counties to 1985*. Financial and Population Research Unit, Sacramento, CA.

____ (1971). *Provisional Projections of California Counties to 2000*. Population Research Unit, Sacramento, CA.

____ (1977). *Population Projection for California Counties: 1975-2020*. Report 77-P-3, Sacramento, CA.

____ (1983). *Projected Total Population of California Counties: 1980-2020*. Report 83 P-1. Population Research Unit, Sacramento, CA.

____ (1986). *Projected Total Population of California Counties 1985-2020.* Report 86 P-1. Population Research Unit, Sacramento, CA.

____ (1991). *Interim Population Projections for California State and Counties 1990-2005*. Report 91 P-1. Official State Projections. Sacramento, CA.

____ (1998a). *Census of California Counties: 1850-1990*. Sacramento, CA.

____ (1998b). *Intercensal Estimates of Total the Population of California Counties*. Report I, 70-80, 80-90, 90-97. Sacramento, CA.

____ (1962). *Preliminary Projections of California Areas and Counties to 1975*. Financial and Population Research Unit, Sacramento, CA.

California Energy Commission (1998). *California Petrolium Transportation Fuels Price Forecast*. Staff Working Paper. By James M. Page, Fuel Resources Office, Energy Information and Analysis Division, Sacramento, CA (February).

Cameron, M. (1991). *Transportation Efficiency: Tackling Southern California's Air Pollution and Congestion*. Environmental Defense Fund, Los Angeles (March).

Campbell, C. J. and J. H. Laherrere (1998). The end of cheap oil. *Scientific American,* (March).

Cambell, P. R. (1996). *Population Projections for States by Age, Sex, Race, and Hispanic Origin: 1995 to 2025*, U.S. Bureau of the Census, Population Division, PPL-47.

Center for Continuing Study of the California Economy (1997). *California County Projections*. Palo Alto, CA.

Center for Continuing Study of the California Economy (1999). *California Economic Growth.* Palo Alto, CA.

DKS & Associates. (1994). *SACMET Regional Travel Demand Model Version 94.0: Model Development and User Reference Report*. SACOG. Sacramento, CA.

Energy Information Admistration (1998). *Annual Energy Outlook*. Energy Information Administration. Office of Integrated Analysis and Forecasting. U.S. Department of Energy, Washington, D.C.

Ewing, R. (1997). Is Los Angles-style sprawl desirable*? Journal of the American Planning Association, 63:1 (Winter),* 107-126.

Harvey, G. and E. Deakin (1995). *Description of the STEP Analysis Package*. Berkeley, CA.

Johnson, H. J. (1999). How many Californians? A review of population projections for the state. *California Counts. Population Trend and Profiles*. Public Policy Institute of California, *1:1* (October).

Kessler J. and W. Schroeer (1995). Meeting mobility and air quality goals: Strategies that work. *Transportation, 22,* 241-272.

Keyfitz, N. (1981). The limits of population forecasting. *Population and Development Review, 7,* 579-593.

Kitigawa, E. M., and B. D. Spencer (1981). On Estimating Population and Income for Local Areas. U.S. Department of Commerce, *Statistical Reporter,* 81-88.

Pflaumer, P. (1988). Confidence intervals for population projections based on Monte Carlo methods. *International Journal of Forecasting, 4,* 135-142.

Rodier, C. J. (2000). Confidence intervals for population projections of California counties based on an empirical analysis of past projection error. Department of Environmental Science and Policy, University of California, Davis, CA 95616.

Sacramento Area Council of Governments (1996). *1995 Regional Housing, Population, & Employment Projections, Documentation and Analysis.* Sacramento, CA, (February).

Sacramento Area Council of Governments (1998). Conformity Analysis of the 1996 Metropolitan Transportation Plan, (May).

Sacramento Area Council of Governments (1999). Conformity Analysis of the 1999 Metropolitan Transportation Plan, (June).

Smith K. S. (1986). Accounting for Migration in Cohort-Component Projections of State and Local Populations. *Demography*, *23*, 127-135.

Smith K. S. (1987). Tests of forecast accuracy and bias for country population projections, *Journal of the American Statistical Association*, *83*, 991-1003.

Smith K. S. and S. Cody (1994). Evaluating the housing unit method. A case study of 1990 population estimates in Florida. *Journal of the American Planning Association, 60: 2* (Spring), 209-221.

Smith K. M. and T. Sincich (1988). Stability over time in the distribution of population forecasts errors. *Demography*, *25: 3*, 461-474.

Smith K. M. and T. Sincich (1991). An empirical analysis of the effect of length of forecast horizon on population forecast errors. *Demography*, *28: 2,* 261-274.

Stopher P. R. and A. H. Meyburg (1975). *Urban Transportation Modeling and Planning*. D.C. Heath and Company.

Stoto, M. (1983). The accuracy of population projections, *Journal of the American Statistical Association*, *78*, 13-20.

Tayman, J. (1992). An evaluation of subcounty population forecasts. *URISA Conference Proceedings*, *4*, 172-181.

Thompson, D., M. Baker, and D. Wade (1997). Conformity: long-term prognoses for selected ozone nonattainment areas in California. Preprint for the Transportation Research Board 76th annual meeting, Washington, D.C. (January).

UCLA (1998). *The UCLA Anderson Forecast*. The Anderson School at UCLA. Los Angles, CA

U.S. Bureau of the Census (1985). Evaluation of the Subcounty Population Estimates. *Current Population Reports*, Series P-25, No. 963, Washington, DC.

U.S. Department of Commerce, Bureau of Economic Analysis (1995). *BEA Regional Projections to 2040; Volume 1, States*. Washington DC: U.S. Government Printing Office.

CHAPTER THREE

AIR QUALITY ANALYSIS OF TRANSPORTATION PLANS: IS IT IMPORTANT TO MODEL THE LAND USE EFFECTS?

by

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

Abstract:

In this study, we isolate the contribution that the representation of the land use and transportation interaction in an urban model makes to travel and vehicle emissions analyses of transportation scenarios in the Sacramento region over 25- and 50-year time horizons. One of the more theoretically consistent and practical operational urban models, MEPLAN, is used to simulate trend base case, high occupancy vehicle lanes (HOV), beltway freeways, and light rail and auto pricing scenarios. These transportation scenarios are simulated, first, with the full MEPLAN model to represent the land use and transportation interaction of the scenarios and, second, with the distribution of activities held constant from the future base case scenario so that the interaction is not represented. Vehicle emissions analyses are conducted with the California emissions model (DTIM2). The errors due to the failure to represent the land use changes for the light rail and pricing scenarios are small because of the comparatively limited range of the light rail network and auto pricing policies. However, the failure to represent the land use and transportation interaction from the HOV and Beltway scenarios significantly altered the magnitude of change for both travel and emissions results and the rank ordering of scenarios for emissions results. This error increases over time but is significant in the 25-

year time horizon for both the HOV and the Beltway scenario. The HOV lane scenario was designed to include projects that are typical for a 20-year regional plan.

I. Introduction

Within the last decade, U.S. legislation and regulations have provided a mandate for planning agencies to analyze the relationship between land use and transportation decisions. The Transportation Equity Act for the 21st Century of 1998 (TEA-21) urges transportation planning to consider the effects of transportation policy decisions on land use and economic development. The U.S. Environmental Protection Agency's (EPA) conformity regulations for the Clean Air Act Amendments of 1990 (CAAA) require a logical correspondence between future regional land use projections and transportation plans in serious or worse non-attainment regions (40 CFR 93.122(b)(1)(iii)). Recently, a U.S. District Court case in the Chicago region held that the National Environmental Policy Act (NEPA) requires the consideration of land development changes when a new freeway segment is analyzed.

The history of urban development and transportation technology seems to provide clear evidence for the land use and transportation interaction. When rail first appeared in cities, the central area around stations grew dramatically. As new technology reduced travel time and costs to more areas, as with the streetcar and then the automobile, cities began to decentralize until low-density suburban development became the norm for the modern metropolitan area. However, recently in the U.S. some have questioned the *current* significance of the relationship between land use and transportation and its effect on travel patterns and vehicle emissions (Transportation Research Board, 1995).

In this study, we evaluate the contribution that the representation of the land use and transportation interaction in an urban model makes to travel and vehicle emissions analyses of transportation scenarios in the Sacramento region for 25- and 50-year time horizons (from 1990 to 2015 and 2040). One of the more theoretically consistent and practical operational urban models, MEPLAN (Wegener, 1994), is used to simulate future base case, high occupancy vehicle (HOV) lanes, beltway freeways, and light rail and auto pricing scenarios. These transportation scenarios are, first, simulated with the full MEPLAN model to represent the land use and transportation interaction in the scenarios. Next, the same scenarios are simulated with the MEPLAN travel demand model, but the spatial distribution of activities is held constant from the future base case across all scenarios. In this way, we evaluate the contribution that the land use and transportation interaction makes to the rank ordering of the scenarios and magnitude of change among the scenarios with respect to travel and emissions analyses in the Sacramento MEPLAN model.

The Sacramento MEPLAN model has been developed as part of a larger project to compare alternative land use models on a consistent basis in the U.S. The MEPLAN framework draws on over 25 years of spatial economic modeling experience and has been used around the world (Hunt and Echenique, 1993), but the Sacramento model is the first application in the U.S. Moreover, this is one of the first studies in which an integrated land use and transportation model uses separate AM, PM, and off-peak assignment models (as opposed to an average daily assignment model) for more accurate emissions analysis. The California Department of Transportation's DTIM2 model is used for the emissions analysis.

II. Deficiencies of Land Use Projections Used by Regional Planning Agencies

Most regional planning agencies in the U.S. develop a single set of land use projections for each time horizon used in their travel and emissions models. The consensus-based process by which the typical regional planning agency develops its land use projections (zonal-level population and employment forecasts) includes gathering data from local jurisdictions (e.g., building permits and general plans) and incorporating the long range expectations of planners and politicians (Waddell, 1995). The land use projections produced by this process have a number of deficiencies, as outlined by Paul Waddell:

1. Forecasts based on consensus about planned developments and development trends are likely to reflect an emphasis on supply side at the expense of demand side considerations.

2. The impact of public policies on development (e.g., school quality, municipal services, and taxing policies) must be dealt with in an ad hoc fashion, since no systematic way of quantifying their impact is typically used.

3. Disagreements over outcomes in the forecast are difficult to resolve because there is no quantified relationship between input assumptions and forecasting outcomes.

4. Disagreements or changes in the forecast that have distributional consequences across jurisdictions must be addressed by negotiation rather than a quantitative assessment of the likely impact area (e.g., from a new freeway).

5. The inconsistency of jurisdictional forecast allocation procedures to transportation zones suggests that it would be difficult to test sensitivity of land uses to transportation system alternatives with any degree of consistency and confidence.

To summarize, the typical consensus-based approach used by regional planning agencies to develop land use projections does not adequately represent the effect of transportation plans on the future location of employment and population location and is subject to numerous inaccuracies and biases.

III. Current Legislative and Regulatory Mandates

Recent legislation and regulations require planning agencies to analyze the relationship between land use and transportation decisions. TEA-21 states that transportation planning should consider the effects of transportation policy decisions on land use and economic development. The CAAA mandate the conformity of state air quality plans and transportation plans. Non-attainment regions are required to use travel demand models to demonstrate that the aggregate emissions levels in their transportation improvement plan are not greater than the motor vehicle emissions budget in the approved state implementation plan. Continuous monitoring to verify attainment and maintenance of emissions budgets as well as periodic conformity assessments are also required. Thus, it is important that regional travel and emissions analyses account for potential changes in emissions that may result from the effects of transportation investment decisions on urban form and the effects of changes in urban form on travel. A logical correspondence between future regional land use projections and transportation plans in serious or worse non-attainment regions is required by EPA's conformity regulations (40 CRF 93.122(b)(1)(iii)). In addition, the CAAA allows for the evaluation of land use policies that may reduce vehicle travel and emissions. If the requirements of the CAAA are not met, penalties can be imposed, including the loss of federal funds for transportation projects, the imposition of stricter requirements, and possibly litigation.

Elizabeth Deakin (1995) reports that the same questions surrounding the land use effects of transportation investment decisions that TEA-21 and the CAAA require planning agencies to answer are also raised by the public in local meetings in regions where there are proposals to make major transportation investments. For example, many regions are currently considering new beltway freeways and major transit investments and local 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 (Deakin, 1995).

The outcome of recent litigation has also supported the importance of representing the interaction of transportation projects with land use. In litigation in the San Francisco Bay Area *(The Sierra Club vs. the Metropolitan Transportation Commission*, 1990), the district court endorsed the land use and transportation interaction and required the Metropolitan Transportation Commission to account for this interaction in its regional travel and emissions analyses. Recently, a U.S. District Court case in the Chicago region held that the NEPA requires the consideration of land development changes when a new freeway segment is analyzed. Moreover, peer reviews of regional travel demand models in regions with air quality problems and plans for significant freeway expansions are recommending that regional planning agencies represent the effect of their transportation plans on land uses (e.g., Wasatch Front Regional Council, 1999; Georgia Regional Transportation Authority, 1999).

The deficiencies of land use projections typically used by regional planning agencies do not meet the requirements of CAAA, NEPA, and TEA-21. It is not unreasonable to expect an increase in lawsuits aimed at slowing or halting new highways, unless the land use and transportation interaction is addressed in travel analyses of regional transportation plans.

IV. The Controversy Over the Land Use and Transportation Interaction

Recently, the current significance of the land use and transportation interaction has been challenged by a prestigious committee of transportation researchers (TRB committee) in the Transportation Research Board Special Report No. 245, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use* (1995) (TRB 245). They examined the question of induced auto travel resulting from highway capacity expansion and its effect on air quality and energy use. Numerous studies of the land use and transportation interaction were reviewed, and the researchers concluded:

> In general, currently planned expansions of existing highway networks in built-up metropolitan areas are not as likely to result in major structural changes in metropolitan development patterns for the following reasons: (a) metropolitan areas are not expected to grow as fast as they have in the past; (b) there exists a durable built environment structured around highway travel; and (c) an extensive highway network is already in place, and the general level of accessibility it provides is unlikely to change without major new technological advances.

The conclusion reached by the TRB committee was based on empirical and modeling studies. Their review of the empirical literature found that the effect of changes in the transportation system on land use and the magnitude of this effect are difficult to isolate because of great difficulties controlling for confounding variables. They also review the modeling literature, which lacks the realism of empirical studies but can hold constant potentially confounding variables. They cited two studies in particular and found that changes in the transportation system affect land uses but that over a 20-year projection period the changes in densities, auto travel, and air quality may be small. First, in Southern California sensitivity analyses of the DRAM/EMPAL (or ITLUP) model "indicate that over a 20-year forecast period a 20 percent change in travel time results in changes in residential densities of between 1.5 and 5 percent, depending on household income" (Putman 1993). Second, in the San Francisco Bay Area the Association of Bay Area Governments (ABAG) simulated the land use effects of highway capacity expansion projects included in the MTC's 1989 transportation plan with its POLIS model. It was found that the difference in the locations of jobs and housing between the build and no-build scenarios for the year 2010 was less than 1 percent.

In a minority statement in TRB 245, Michael Replogle questions the validity of these studies for a number of reasons. First, he states that "less-than-state-of-the-art land use models" were used and lists the deficiencies of the DRAM/EMPAL model: "… the models used in the United States have mostly failed to represent land and rent values, the variable quality of key public services (education, public safety), and the potential for mixed-use cluster development around nodes of high public transportation accessibility." In addition, Steven Putman, the developer of the DRAM/EMPAL model, has recently corrected an error in the algorithm used to compute the effect of transportation service on residential location, which made residential location insensitive to accessibility. Second, Replogle states that "the land use models cited were generally calibrated on very short time-series data, often 1980-1985 or 1985-1990, when substantial 'hot' savings and loan money was diverted into highly speculative and often not economically viable real estate development, leading to drastic over-building in many markets." Third, he points out that "the results of model evaluations have usually been predicated on exogenous constraints related to zoning and limitation of redevelopment, giving little room for differences between transportation investment scenarios to express themselves." These exogenous constraints are often later changed in the face of development pressures resulting (in part) from new transportation infrastructure. All of these factors would tend to underestimate the effect of changes in the transportation system on land use, auto travel, and air quality.

A report in the U.K equivalent to TRB 245, *Trunk Roads and the Generation of Traffic* by the Standing Advisory Committee (SACTRA) (1994), also reviewed the evidence on the land use and transportation interaction and came to very different conclusions. The SACTRA found that highway capacity expansion does promote low-density and sprawling land use patterns, which produce an increase in auto travel: "We conclude that the preceding results of published research demonstrate the following important finding, to a reasonable level of confidence … the land-use changes consequent on improved access are likely, in turn, to lead to changes in the patterns of travel, car dependence, and the volume of traffic."

The discrepancy between the conclusions reached by the SACTRA and the TRB committee can be explained in large part by the level of scientific evidence that the respective committees were willing to accept in making their determinations. The TRB committee reviews numerous recent studies in the U.S. regarding the effect of transportation investment on land use patterns. Many of these studies support the relationship, but some do not. In general, however, the TRB committee challenges the methods and rejects the scientific validity of these studies. On the other hand, the SACTRA (1994) recognizes that, with respect to the land use and transportation interaction, "definite proof that would be acceptable to everybody may not ever be possible." They identify five key research difficulties:

1. the detection of statistically significant change due to one specific factor against a background in which there can be substantial (but unknown) day-to-day variations in traffic levels and significant measurement errors;

2. the attribution of cause and effect, given that transport infrastructure improvements often are associated with the other measures at the same time

and that infrastructure changes may provide a necessary, but insufficient, condition for causing traveler responses;

3. the different time scales of different responses (e.g., route changes may happen swiftly but changes to the pattern of origins and destinations are likely to take longer to come into effect), coupled with the problem that other extraneous changes may intervene before the adaptation are complete;

4. the definition of suitable control sites that are independent and representative; and

5. the very large sample sizes and expense that would be necessary to obtain conventional levels of statistical significance in distinguishing between changes in trip frequency and changes in origins and/or destinations.

The SACTRA conclude that for the above reasons it is inherently difficult to prove the phenomena definitively and that to require such proof is not in “the best interest of unbiased appraisal.” They state that their determination is based on “the balance of evidence for and against, rather than on the principle that the current procedures should stay until there is conclusive proof of both the existence and the size of the phenomenon.”

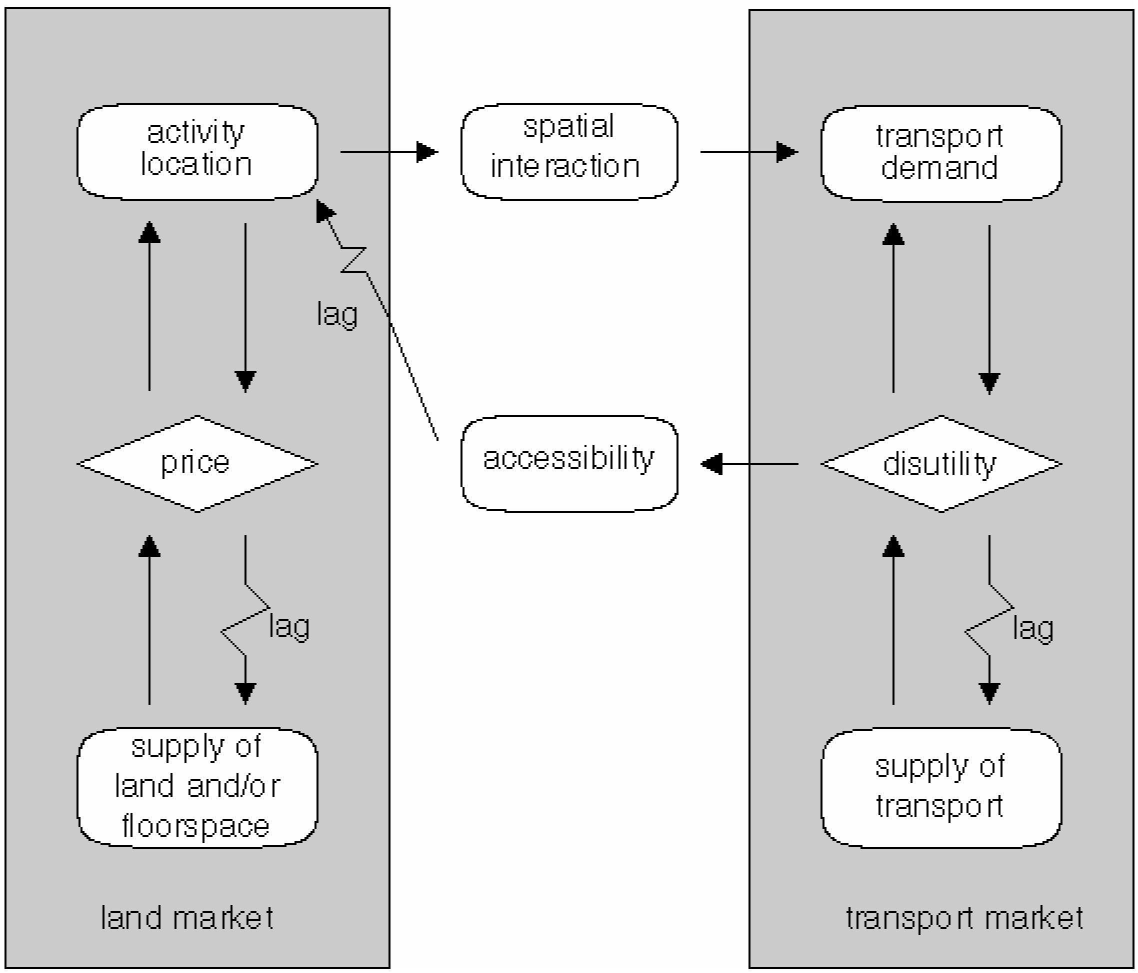
The level of evidence required by the TRB committee and the SACTRA to affirm the land use and transportation interaction reflects a value judgement. Given the health risks due to air pollution and the potential catastrophic effects of global climate change, what is society willing to give up now, perhaps even unnecessarily, to protect the environment for future generations? The TRB committee’s decision to accept only a high level of evidence for the land use and transportation interaction suggests that they place a higher value on the perceived economic benefits of highway expansion than on avoiding its potential negative environmental effects. The SACTRA, however, appears to be more highly averse to the negative environmental consequences of highway capacity expansion and places a comparatively lower value on economic benefit from highway expansion. The requirements of the TEA-21 and the CAAA legislation suggest that the same is true for the U.S. public, as expressed through their representatives in Congress.

V. Methods

A. The Sacramento MEPLAN Model

The basis of the MEPLAN modeling framework is the interaction between two parallel markets, the land market and the transportation market. This interaction is illustrated in Figure 3.1. Behavior in these two markets is a response to price signals that arise from market mechanisms. In the land markets, price and generalized cost (disutility) affect production, consumption, and location decisions by activities. In the transportation markets, money and time costs of travel affect both mode and route selection decisions.

Figure 3.1. The interaction of the land use and transportation markets in MEPLAN



The cornerstone of the land market model is a spatially-disaggregated social accounting matrix (SAM) (Pyatt and Thorbecke, 1976) or input-output table (Leontieff, 1941) that is expanded to include variable technical coefficients and uses different categories of space (e.g., different types of building and/or land). Logit models (McFadden, 1974) of location choice are used to allocate volumes of activities in the different sectors of the SAM to geographic zones. The attractiveness or utility of zones is based on the costs of inputs to the producing activity (which include transportation costs), location-specific disutilities, and the costs of transporting the resulting production to consumption activities. The resulting patterns of economic interactions among activities in different zones are used to generate origin-destination matrices of different types of trips. These matrices are loaded to a multi-modal network representation that includes nested logit forms (Williams, 1977) for the mode choice models and stochastic user equilibrium for the traffic assignment model (with capacity restraint). The resulting network times and costs affect transportation costs, which then affect the attractiveness of zones and the location of activities, and thus the feedback from transportation to land use is accomplished.

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

MEPLAN.

The specific structure of the Sacramento MEPLAN model is shown in the diagram in Figure 3.2, and Table 3.1 defines the categories in the diagram. The large matrix in the middle of the diagram lists the factors in the land-use sub-model and describes the nature of the interaction between factors. A given row in this matrix describes the consumption needed to produce one unit of the column factor, indicating which factors are consumed and whether the rate of consumption is fixed (f) or price elastic (e).

Figure 3.2. Diagram of the Sacramento MEPLAN model.

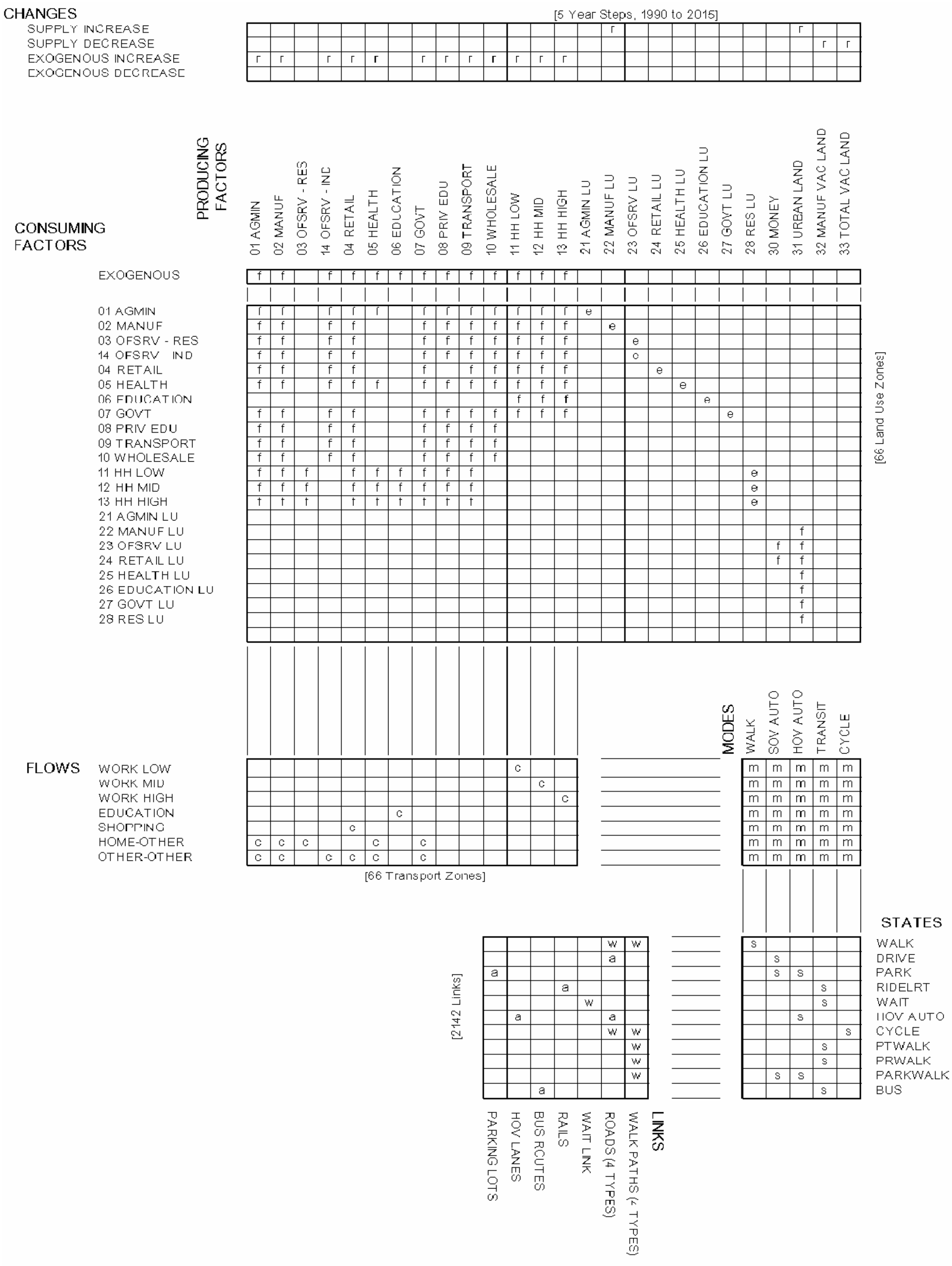


Table 3.1. Description of categories in the figure 2 diagram.

Type of Category	Category Name	Category Description
Industry and Service	AGMIN	Agriculture and mining
	MANUF	Manufacturing
	OFSRV-RES	Services and office employment consumed by households
	OFSRV-IND	Services and office employment consumed by other industry
	RETAIL	Retail
	HEALTH	Health
	EDUCATION	Primary and secondary education
	GOVT	Government
	PRIV EDU	Private education
	TRANSPORT	Commercial transportation
	WHOLESALE	Wholesale
Households	HH LOW	Households with annual income less than $20,000
	HHMID	Households with annual income between $20,000 and $50,000
	HH HIGH	Households with annual income greater than $50,000
Land Use	AGMIN LU	Land used for agriculture
	MANUF LU	Land used for manufacturing
	OFSRV LU	Land used for services and office employment
	RETAIL LU	Land used for retail
	HEALTH LU	Land used for health
	EDUCATION LU	Land used for education
	GOVT LU	Land used for government
	RES LU	Land used by residences

The Sacramento MEPLAN model uses eleven industry and service factors that are based on the SAM and aggregated to match employment and location data. Households are divided into three income categories (high, medium, and low) based on the SAM and residential location data. The consumption of households by businesses represents the purchase and supply of labor. The consumption of business activities by households represents the purchase of goods and services by consumers. Industry and households consume space at different rates and have different price elasticities, and thus there are seven land use factors in the model. Constraints are placed on the amount of manufacturing land use to represent zoning regulations that restrict the location of heavy industry. Each of these land uses (except agriculture land use) locates on developed land represented by the factor URBAN LAND. Two factors are used to keep track of the amount of vacant land available for different purposes in future time periods (MANUF VAC LAND and TOTAL VAC LAND) and the development process converts these two factors to URBAN LAND. The MONEY factor is a calibration parameter that allows differential rents to be paid by different users of the same category of land.

The single-row matrix just above the large matrix in Figure 3.2 shows activity that is demanded exogenously, which includes exporting industry, retired households, and unemployed households. This corresponds to the "basic" economy in the Lowry model.

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

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

The remaining three matrices at the bottom show the structure of the transportation model. Five modes are available, and each mode can consist of several different types of activity on different types of links. The matrix directly to the right shows that all modes are available to all flows (m). The matrix below this, on the right, indicates the travel states (s) that make up each mode. The matrix on the left shows which travel states are allowed on each transportation network link and whether capacity restraint is in effect (a) or not (w). The design of the mode choice and assignment models is based on the Sacramento Regional Travel Demand model (DKS Associates, 1994). A more detailed description of the model design can be found in Abraham (2000).

B. Emissions Model

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) emissions model and the California Air Resources Board's EMFAC7F emissions factors are used in the emission analysis. The outputs from the MEPLAN model used in the emissions analysis include the results of assignment for each trip purpose by each time period (AM peak, PM peak, and off-peak). The Sacramento Area Council of Governments (SACOG) provides regional cold-start and hot-start coefficients for each hour in a twenty-four hour summer period. The 2015 emissions factors are used for the 2015 scenarios, and the 2020 emissions factors are used for the 2040 scenarios. The 2020 factors were the latest available from EMFAC7F.

VI. Scenarios

All the transportation network improvements are made in the year 2005, and thus land use is affected in the years 2010 to 2040 (in five-year increments). For the 2015 scenario, land uses are affected in only one five-year time increment. See Figure 3.3 for a map of the scenario networks.

Base Case. The base case scenario represents a financially conservative expansion of the Sacramento region's transportation system and serves as a point of comparison for the other scenarios examined in this study. This scenario includes a relatively modest number of road-widening projects, new major roads, one freeway HOV lane segment, and a limited extension of light rail.

High Occupancy Vehicle (HOV). The HOV lane scenario represents an extensive expansion of the Sacramento region's HOV lane system to encourage the use of carpools. HOV lanes are increased from 26 lane miles in the Base Case scenario to 179 lane miles in the 2015 HOV lane scenario. Mixed-flow freeway lanes are increased by 6 percent compared to the Base Case scenarios. This scenario is designed to represent a typical roadway oriented regional transportation plan.

Beltway Freeways. The beltway scenario adds two regional beltways (in the north, south, and east areas of the region) to the HOV scenario and includes 591 new lane miles of freeways, six new interchanges for the beltways, and 65 lane miles of new arterial roads to serve the beltways. This scenario represents a 54 percent increase in new freeway lane miles and HOV lane miles over the Base Case scenario.

Light Rail & Pricing. In this scenario, 75 new track miles of light rail are added to the transportation network, and auto-pricing policies are also imposed. These pricing policies include a 30 percent increase in the operating cost of private vehicles (to simulate a gas tax) and a central business district (CBD) parking tax representing an average surcharge of $4 for work trips and $1 for other trips.

Figure 3.3. Sacramento scenario network map.

VII. MEPLAN Results

Using the MEPLAN model, the four transportation scenarios were simulated, first, with the full model set to represent the land use and transportation interaction, and second, with the distribution of activities held constant from the Base Case scenario so that the interaction would not be represented. The discussion of the results in this section describes the land use results from simulations that included the interaction and then compares the travel and emissions results from the scenarios simulated with and without the interaction.

A. Land Use

The land use results are presented in Table 3.2. In the Base Case scenario, land development from 1990 to 2015 and 2040 occurs north, east, and south of the City of Sacramento. There is limited land development in Yolo County because of exclusive agricultural zoning in the county. Over time for both the 2015 and 2040 time horizons, households and employment tend to locate primarily in existing, built-up areas northeast, east, and immediately south of the CBD. In 2040, however, households are more likely to locate in relatively more remote sections of these areas (e.g., South Sutter, Southeast Sacramento County, and El Dorado Hills). In general, household and employment location tends to follow land development; however, density increases in some zones. The land use results for the other scenarios are discussed in comparison to the future Base Case scenarios.

Table 3.2. Percentage change from the base case scenario to the scenarios by superzone.

	2015			2040		
HOUSEHOLDS (thousands)	HOV	Beltway	Light Rail & Pricing	HOV	Beltway	Light Rail & Pricing
Sacramento CBD (13, 15,50)	1%	1%	2%	1%	2%	1%
Citrus Hgts/Roseville (70,71,4)	2%	1%	1%	2%	2%	2%
Rancho Cordova/Folsom (6,12)	-1%	0%	1%	0%	1%	1%
Inner Suburbs (1-3,7-11,14,16,25)	1%	2%	1%	2%	2%	2%
Outer Ring (remainder)	-1%	-1%	-1%	2%	2%	2%
EMPLOYMENT (thousands)	HOV	Beltway	Light Rail & Pricing	HOV	Beltway	Light Rail & Pricing
Sacramento CBD (13, 15,50)	3%	4%	-3%	5%	3%	-3%
Citrus Hgts/Roseville (70,71,4)	-6%	1%	0%	-8%	0%	1%
Rancho Cordova/Folsom (6,12)	14%	12%	3%	21%	18%	-1%
Inner Suburbs (1-3,7-11,14,16,25)	2%	3%	3%	5%	5%	3%
Outer Ring (remainder)	-9%	-12%	1%	5%	6%	0%

The land use results for the HOV and the Beltway scenarios are generally similar but the shifts tend to be more dramatic in the Beltway scenario than in the HOV lane scenario. Roadway expansion in the HOV and the Beltway scenarios allows industry to locate further away from the households that it serves and employs. Employment location is more intense in the existing, built-up areas northeast, east, and immediately south of the CBD, and in the CBD for both the 2015 and 2040 time horizons. Differences in employment location, however, are more dramatic in 2015 than in 2040, and the opposite is true for households. In 2015 there is a movement of households further away from employment compared to the Base Case; however, this shift is more intense by 2040, as more households locate in the most remote eastern sections of the region (e.g., Placer High, High Country, Grizzly Flat, and Pollock Pines).

Businesses are moved around more easily than households in the Sacramento MEPLAN model in the shorter term. First, the model allows businesses in the presence of higher rents, to use less space. Second, the model does not include a floorspace submodel, and thus differences among types of commercial buildings cannot be distinguished and there is no cost to redevelop a building space. As a result, it is relatively easy for the model to show retail operations to moving into a former warehouse or an office moving into a former retail space. A floorspace model would better simulate the difficulty of such moves by distinguishing among building types and representing the time and money needed to redevelop buildings for new use.

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

In the Light Rail & Pricing scenario for both the 2015 and 2040 time horizons, the parking charges in the CBD result in a loss of employment, as businesses relocate to nearby zones to avoid the parking charges. There is also a gain in households because commercial activities are no longer willing to outbid residential activities. The increased mobility over short distances in central zones allows for a greater separation between households and employment. This is similar to what was found in the HOV lane and Beltway scenarios, but the effect is much smaller and only occurs in the most central zones where light rail service is very good. For both time horizons, households and employment generally tend to shift to zones that follow the light rail lines from zones without light rail service. Again, the shift in employment is more dramatic in 2015 than in 2040 and the shift in households is more dramatic in 2040 than in 2015. However, the shifts tend to be smaller in the light rail scenario than in the HOV and beltway scenario. This is because the light rail expansion is less extensive than the HOV lane and beltway freeway expansions.

B. Travel Results

In the HOV and Beltway scenarios in which the land use and transportation interaction was simulated, the greater distance between the home and workplace generally tends to produce a shift from the drive alone, walk, and bike modes to the carpool and transit modes. The percentage change in daily mode share projections for the 2015 and 2040 scenarios are presented in Tables 3.3 and 3.4. Note that Scenario Set A includes the land use and transportation interaction and Scenario Set B holds land uses constant from the Base Case across all scenarios. Travelers take advantage of the faster travel speeds provided by the HOV lanes and carpool or use commuter buses (also allowed on HOV lanes). This is generally true for both the 2015 and 2040 time horizons with the exception of the 2015 HOV lane scenario. In this scenario, the travel speeds for the carpool mode are faster than those of transit, and thus transit share is slightly reduced. Shifts in mode shares are more dramatic in the Beltway scenario than in the HOV lane scenario because the distance between work and home tends to be greater and auto travel speeds are faster in the Beltway scenario compared to the HOV lane scenario. The carpool and transit mode shares experience a larger increase in 2040 than in 2015 (compared to the Base Case) because heavier regional travel volume slows travel speeds on mixed-use lanes and makes the carpool and transit modes more competitive with the drive alone mode. The walk and bike mode shares experience larger reductions in the 2040 scenarios than in the 2015 scenarios because of faster travel times by auto and transit and the degraded jobs-housing balance over time.

Table 3.3. 2015 MEPLAN scenarios: percentage change in daily mode share.

Scenarios	*A* Land use and transport interaction				*B* Land use held constant			
	Drive Alone	Carpool	Transit	Walk & Bike	Drive Alone	Carpool	Transit	Walk & Bike
HOV	-2.7%	4.3%	-1.4%	-5.9%	-1.0% (1.7%) [a]	2.5% (-1.7%)	-5.8% (-4.4%)	-5.5% (0.5%)
Beltway	-3.2%	5.4%	3.6%	-9.0%	-0.8% (2.5%)	2.6% (-2.7%)	-4.3% (-7.6%)	-7.2% (2.0%)
Light Rail & Pricing	-6.9%	6.5%	19.4%	2.2%	-7.6% (-0.7%)	7.3% (0.8%)	19.4% (0.0%)	1.6% (-0.6%)

[a] Figures in parentheses are percentage point change for the same scenario (*B* - *A*).

Table 3.4. 2040 MEPLAN scenarios: percentage change in daily mode share.

Scenarios	*A* Land use and transport interaction				*B* Land use held constant			
	Drive Alone	Carpool	Transit	Walk & Bike	Drive Alone	Carpool	Transit	Walk & Bike
HOV	-3.3%	7.6%	16.5%	-15.6%	-1.0% (2.4%) [a]	3.9% (-3.4%)	5.2% (-9.7%)	-10.6% (6.0%)
Beltway	-3.6%	8.4%	14.8%	-17.2%	-0.9% (2.8%)	4.7% (-3.4%)	0.0% (-12.9%)	-13.5% (4.5%)
Light Rail & Pricing	-4.6%	4.1%	21.7%	1.5%	-5.3% (-0.7%)	5.1% (0.9%)	21.7% (0.0%)	0.8% (-0.7%)

[a] Figures in parentheses are percentage point change for the same scenario (*B* - *A*).

In the 2015 HOV and the Beltway scenarios that do not include the transportation and land use interaction, the new HOV lanes in both scenarios afford faster travel speeds for the carpool mode and produce a shift from the drive alone, transit, walk, and bike modes to the carpool mode. In 2040, these scenarios produce a larger shift from the drive alone, walk, and bike modes to both the carpool and transit modes in the HOV lane scenario and to the carpool mode only in the Beltway scenario. Again, heavier regional travel volumes in 2040 degrade travel times on mixed-use lanes and make travel speeds by carpool and transit more competitive with the drive alone mode. Changes in auto travel time are the only variables affecting mode share in these scenarios, and thus differences among them are not large. Auto travel speeds are somewhat faster in the Beltway scenarios than in the HOV lane scenarios, and thus shifts in mode are somewhat greater in the Beltway scenarios than in the HOV lane scenarios.

When the land use and transportation interaction is represented in the simulation of the HOV and Beltway scenarios, the magnitude of change (from the Base Case) for mode share is significantly greater for many modes. Note that a result is determined to be significant when the error due to the failure to represent the land use and transportation interaction is greater than the percentage change from the Base Case to the alternative scenarios, in which the interaction is not represented. The simulation of the scenarios that did not include the land use and transportation interaction underestimates the carpool and transit mode shares and overestimates the drive alone, walk, and bike modes. These error trends are true for both the 2015 and the 2040 time horizons, but error is greater in the latter time horizon.

In the Light Rail & Pricing scenarios (2015 and 2040) that include the land use and transportation interaction, there is an increase in mobility over short distances in central zones, where light rail service is very good; however, this increase is less dramatic than in the HOV lane scenario. The greater separation of home and work, the availability of high quality rail service, and the increase in auto operating costs serve to increase transit mode share significantly and to reduce drive alone mode share. The carpool mode share increases in this scenario because carpooling allows the cost of travel to be shared. Walk and bike mode share also increases because of the higher costs of auto travel and increased transit access.

Similar mode shift trends are found in the Light Rail & Pricing scenarios (2015 and 2040) that do not include the land use and transportation interaction. Auto pricing policies and fast transit travel times reduce the drive alone mode and increase the carpool, transit, walk, and bike modes. These scenarios are somewhat more effective than the policies that include the land use and transportation interaction. This is because the effect of the auto pricing policies are not mitigated by land use shifts (see land use discussion of the effects of the parking pricing policies). From 2015 to 2040, the Light Rail & Pricing scenarios in both Scenario Sets A and B become less effective at reducing drive alone mode share and increasing transit, carpool, walk, and bike mode share. This is because light rail serves a relatively limited portion of the region’s population and as it grows over time, this portion becomes even smaller. Note that the service range of the light rail is much more restrictive than the HOV and Beltway network (see Figure 3.3). In general, the error due to the failure to represent the land use and transportation interactions is small.

The mode shifts in the HOV and Beltway scenarios, both with and without the representation of the land use and transportation interaction, produce a significant increase in VMT and mean travel speed compared to the Base Case scenario in both 2015 and 2040. The HOV scenarios with the interaction, however, produce an increase in mean travel time while the same scenarios without the interaction produce a reduction. Percentage change in daily vehicle travel projections for the 2015 and 2040 scenarios are presented in Tables 3.5 and 3.6. In the scenarios without the interaction, new roadway capacity increases travel speeds and produces longer auto trips in terms of distance, but shorter average travel times. In the scenarios with the interaction, greater travel distances between home and work, as well as faster travel speeds, produce longer auto trips both in terms of distance and in time. In the HOV and Beltway scenarios without the interaction, VMT and mean travel time are underestimated, and mean travel speed is overestimated. This is true even though drive alone mode shares are overestimated in this scenario, which means that drive alone trip lengths are underestimated considerably. Generally, for VMT and mean travel time, the error due to the failure to represent the interaction is greater than the percentage change from the Base Case to the HOV and Beltway scenarios, in which the interaction is not represented, and this error increases over time. From 2015 to 2040, both sets of scenarios produce greater VMT, mean travel time, and mean travel speed compared to the Base Case scenario. Again, the magnitude of change is greater in the Beltway scenario than in the HOV lane scenario because of more dramatic changes in land use and/or travel times in the Beltway scenario.

Table 3.5. 2015 MEPLAN scenarios: percentage change in daily vehicle travel.

Scenario	*A* Land use and transport interaction			*B* Land uses held constant		
	VMT	Mean Time	Mean Speed	VMT	Mean Time	Mean Speed
HOV	7.0%	7.2%	1.6%	2.7% (4.2%) [a]	-1.5% (8.8%)	3.9% (-2.2%)
Beltway	13.1%	10.4%	4.6%	6.0% (6.7%)	-0.5% (10.9%)	5.4% (-0.8%)
Light Rail & Pricing	-3.2%	-0.2%	1.1%	-3.6% (0.5%)	-0.5% (0.3%)	2.5% (-1.4%)

[a] Figures in parentheses are percentage point change for the same scenario (*B* - *A*).

Table 3.6. 2040 MEPLAN scenarios: percentage change in daily vehicle travel.

Scenario	*A* Land use and transport interaction			*B* Land uses held constant		
	VMT	Mean Time	Mean Speed	VMT	Mean Time	Mean Speed
HOV	12.1%	10.6%	3.0%	5.4% (6.4%) [a]	-1.8% (12.7%)	6.0% (-2.9%)
Beltway	17.9%	11.5%	5.1%	10.2% (7.0%)	-2.4% (14.2%)	9.7% (-4.2%)
Light Rail & Pricing	-5.9%	-3.8%	-0.2%	-5.6% (-0.3%)	-2.4% (-1.4%)	1.7% (-1.9%)

[a] Figures in parentheses are percentage point change for the same scenario (*B* - *A*).

In the Light Rail & Pricing scenarios for both time horizons, VMT and mean travel time are reduced, and mean travel speed is generally increased in the scenarios with and without the land use and transportation interaction (with the exception of a slight decrease for the 2040 scenario in Set A). From 2015 to 2040, both sets of the scenarios become more effective at reducing VMT and mean travel time. However, in 2015, the scenario without the interaction produces somewhat lower VMT and mean travel time than the scenario with the interaction, and in 2040 the opposite is true. In 2015, in the scenario without the interaction, the auto pricing polices are somewhat more effective because their effects are not mitigated by land use shifts (see discussion of the effect of the parking pricing policies in land use results). In 2040, in the scenario with the interaction, land uses locate more intensively along the light rail lines and thus the scenario becomes more effective. There is only a small difference in the magnitude of change between the scenarios with and without the interaction, particularly in comparison to the HOV and Beltway scenario. Again, this is because the service range of the light rail is more restrictive than the HOV and Beltway network.

C. Emissions

In general, the simulation of emissions for the scenarios with and without the land use and transportation interaction follow the travel results described above. The daily emissions results for the 2015 and 2040 scenarios are presented in Tables 3.7 and 3.8. The 2020 EMFAC7F emissions factors are used for the year 2040 because that is the last year available. In both the 2015 and 2040 scenarios that represent the land use and transportation interaction, the Beltway scenario has the highest emissions, followed by the HOV scenario, the Base Case scenario, and finally the Light Rail & Pricing scenario. From 2015 to 2040, the Light Rail & Pricing scenario produces greater reductions in emissions; however, the HOV and Beltway scenarios, despite using lower 2020 emissions factors, produce larger increases in emissions. In the HOV and Beltway scenarios, the new roadway capacity and greater distances between households and employment increase auto travel speeds, VMT, and vehicle hours traveled and thus increase emissions. In the Light Rail & Pricing scenario, new light rail lines, auto pricing policies, and household and activity development along the lines reduce VMT and vehicle hours traveled and thus reduce emissions.

When the scenarios were simulated with land uses held constant, the rank ordering of the scenarios changed compared to the scenarios simulated with the land use and transportation interaction. In 2015, the Beltway scenario had the highest emissions, followed by the Base Case scenario, the HOV scenario, and finally the Light Rail & Pricing scenario. In 2040, both the Beltway scenario and the Base Case scenario have the highest emissions, followed by the HOV scenario, and then the Light Rail & Pricing scenario. The Beltway scenario produces reductions in TOG and PM and increases in CO and NOx compared to the Base Case. The HOV lane scenario produces reductions in TOG, CO, and PM but increases in NOx. From 2015 to 2040, all scenarios tend to provide greater reductions in emissions compared to the Base Case; however, the results for Light Rail & Pricing are better than the HOV and Beltway scenarios. In the 2015 and 2040 HOV and Beltway scenarios, new roadway capacity increases travel speed and VMT but reduces vehicle hours of travel, and thus emissions decrease for some pollutants (e.g., TOG, CO, and/or PM) and increase for others (e.g., CO and/or NOx). NOx emissions tend to increase with VMT. The Light Rail & Pricing scenario reduces travel speed, VMT, and vehicle hours of travel and thus emissions are reduced for all pollutants.

Table 3.7. 2015 MEPLAN scenarios: percentage change in daily vehicle emissions.

Scenarios	*A* Land use and transport interaction				*B* Land uses held constant			
	TOG	CO	NOx	PM	TOG	CO	NOx	PM
HOV	3.6%	3.0%	3.0%	2.6%	-3.2% (-6.6%) [a]	-1.6% (-4.5%)	0.0% (-2.9%)	-4.8% (-7.2%)
Beltway	9.8%	12.1%	12.4%	7.6%	0.51% (-8.5%)	4.3% (-6.9%)	6.0% (-5.7%)	-3.8% (-10.5%)
Light Rail & Pricing	-5.6%	-4.5%	-3.3%	-6.3%	-6.5% (-1.0%)	-4.9% (-0.5%)	-3.5% (-0.2%)	-7.1% (-0.8%)

[a] Figures in parentheses are percentage point change for the same scenario (*B* - *A*).

Table 3.8. 2040 MEPLAN scenarios: percentage change in daily vehicle emissions.

Scenarios	*A* Land use and transport interaction				*B* Land uses held constant			
	TOG	CO	NOx	PM	TOG	CO	NOx	PM
HOV	4.5%	5.0%	6.5%	4.4%	-5.1% (-9.2%) [a]	-1.8% (-6.5%)	1.7% (-4.5%)	-5.0% (-9.0%)
Beltway	9.1%	12.6%	15.9%	5.6%	-2.9% (-11.0%)	3.7% (-7.9%)	9.5% (-5.5%)	-5.3% (-10.4%)
Light Rail & Pricing	-6.4%	-6.0%	-5.5%	-5.9%	-7.5% (-1.2%)	-6.8% (-0.8%)	-5.7% (-0.2%)	-8.1% (-2.4%)

[a] Figures in parentheses are percentage point change for the same scenario (*B* - *A*).

In general, when land uses are not accounted for in the simulation of the scenarios, emissions are underestimated for the Beltway, HOV, and Light Rail & Pricing scenarios compared to the Base Case. When the land use and transportation interaction is not accounted for in the HOV and Beltway scenarios, emissions for some pollutants are projected to decrease rather than increase because of reduced vehicle hours traveled. Again, the error due to the failure to represent the interaction, in many cases, is greater than the percentage change from the Base Case to the HOV and Beltway scenarios in which the interaction is not represented. This error tends to increase over time from 2015 to 2040.

VIII. Summary and Conclusions

In this study, we isolate the contribution that the representation of the land use and transportation interaction in an urban model makes to travel and vehicle emissions analyses of transportation scenarios in the Sacramento region over a 25- and 50-year period (from 1990 to 2015 and 2040). One of the more theoretically consistent and practical operational urban models, MEPLAN (Wegener, 1994), is used to simulate high occupancy vehicle (HOV) lanes, beltway freeways, and light rail and auto pricing scenarios. These transportation scenarios are simulated, first, with the full MEPLAN model to represent the land use and transportation effects of the scenarios and, second, with the distribution of activities held constant from the future Base Case scenario so that the land use and transportation interaction is not represented. Vehicle emissions analyses are conducted with the California emissions model (DTIM2).

Transportation networks for the HOV lane, Beltway, and Light Rail & Pricing scenarios examined in this study are illustrated in Figure 3.3. The beltway and HOV lane network extend significantly farther into the region than does the light rail network. The Beltway scenario represents a major expansion of the region's roadway system; politically and financially, it is unlikely that an expansion of this scope would take place in this region during a 25-year time horizon. However, many other regions are actively pursuing beltway freeways. The HOV lane scenario is intended to represent a typical 20-year regional transportation plan in terms of both type and scope of projects included in the scenario. The Light Rail & Pricing scenario represents light rail expansion that has a reasonable chance of being funded and relatively conservative auto pricing policies that may possibly be implemented.

The scope of each scenario's transportation network and policies is reflected in the absolute change of household and employment activities from the Base Case scenario. On a regional level, these changes are significant for both the HOV and Beltway scenarios but less so for the Light Rail & Pricing scenario. As expected, the change in households and employment for these scenarios is generally significantly larger in 2040 than in 2015.

The failure to represent the land use changes in the Light Rail & Pricing scenario did not significantly alter the magnitude of change or its rank ordering among the scenarios. As just described, the relatively limited range of the light rail network and the limited scope of the auto pricing policies resulted in comparatively modest changes in land use, travel time, and cost. The error does increase over time, but again the error is comparatively small.

However, the failure to represent the land use changes resulting from the HOV and Beltway scenarios does significantly alter the magnitude of change for both travel and emissions results and the rank ordering of scenarios for emissions results. Travel speeds are overestimated and vehicle hours of travel, VMT, and emissions are underestimated when the land use and transportation interaction is not represented in the scenarios. Emissions are projected to decrease for some pollutants in the HOV and Beltway scenarios when land use changes are not simulated, and when they are, emissions are projected to increase for all pollutants. In most instances, the error due to the absence of the interaction is greater than the percentage change from the Base Case to the HOV and Beltway scenarios (without the interaction). This error increases over time from 2015 to 2040, but it is significant in 2015 (the 25-year time horizon) for both the HOV and the Beltway scenarios. As described above, the HOV lane scenario is designed to include projects that are typical for a 20-year regional plan.

In this study, we apply one of the more theoretically consistent and practical operational urban models (MEPLAN) to the Sacramento region. The results show that travel and emissions analyses will contain significant errors in both a 25- and 50-year time horizons for a typical highway-oriented transportation plan, if the land use effects are ignored. This is a case study of the Sacramento region, and it is difficult to generalize to other regions of the country. However, the outcome of this study is in contrast to the outcome of studies in the Bay Area and Los Angeles (ABAG, 1991; Putman, 1993) that used less theoretically sophisticated land use models and more restrictive zoning assumptions. More analyses of the land use and transportation interaction is warranted, particularly given the current legislative and regulatory mandates and the deficiencies of land use projections typically used by regional planning agencies.

As Waddell (1995) points out, the land use projections produced by any currently available land use model would not be credible enough for use in transportation and air quality analyses without some technical review committee (or process) to “legitimize” the projects. In the future, land use models may “improve to the point that they become, to use the earlier metaphor, the majority vote on such a review committee."

REFERENCES

ABAG (1991). Assessing the Future: A Sensitivity Analysis of Highway and Road Improvements on Growth in the San Francisco Bay Area. Working Paper 91-4, Oakland, CA.

Abraham, J. E. (2000). Parameter Estimation in Urban Models: Theory and Application to a Land Use Transport Interaction Model of the Sacramento, California Region. Diss. University of Calgary, Canada.

Deakin, E. (1995). Keynote Address. In Travel Model Improvement Program Land Use Modeling Conference Proceedings. Edited by Shunk, G. A., P. L. Bass, C. A. Weatherby, and L. J. Engelke. Travel Model Improvement Program. U.S. Department of Transportation, U.S. Environmental Protection Agency. (February), 19-21.

DKS Associates (1994). Model Development and User Reference Report. Sacramento Area Council of Governments, Sacramento, CA, (October).

Hunt J. D., and M. H. Echenique (1993). Experiences in the application of the MEPLAN framework for land use and transportation interaction modeling. Proceedings of the 4th National Conference on the Application of Transportation Planning Methods, Daytona Beach, Florida, USA, (May), 723-754.

Hunt, J. D. (1994). Calibrating the Naples land use and transport model. *Environment and Planning 21B*, 569-590.

Georgia Regional Transportation Authority (1999). 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).

Leontieff, W. (1941). *The Structure of the American Economy 1919-1939*, Oxford University Press, New York, NY, USA.

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In *Frontiers in Econometrics*, Editor: Zarembka P. Academic Press, New York, USA, 105-142.

Meyer, M. D., and E. J., Miller (1984). *Urban Transportation Planning: A Decision-Oriented Approach*. McGraw-Hill, New York, USA.

Putman, S. (1993). Sensitivity Tests with Employment and Household Location Models. Presented at the 3rd International Conference on Computers in Urban Planning and Urban Management, Georgia Institute of Technology, GA. (July).

Pyatt, G., and E. Thorbeck (1976). *Planning Techniques for a Better Future*. International Labour Office, Geneva, Switzerland.

Replogle, M. in Transportation Research Board (1995). Expanding Metropolitan Highways: Implications for Air Quality and Energy Use, Special Report. 245. National Research Council, Washington, D. C.

Standing Advisory Committee on Truck Road Assessment (1994). Trunk Roads and the Generation of Traffic. U.K. Department of Transport, December, London.

Transportation Research Board (1995). Expanding Metropolitan Highways: Implications for Air Quality and Energy Use, Special Report 245. National Research Council, Washington, D. C.

Waddell, P. (1995). Summary of Workshop Three. In Travel Model Improvement Program Land Use Modeling Conference Proceedings. Edited by Shunk, G. A., P. L. Bass, C. A. Weatherby, and L. J. Engelke. Travel Model Improvement Program. U.S. Department of Transportation, U.S. Environmental Protection Agency. (February), 19-21.

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

Wegener M. (1994). Operational Urban Models, *Journal of the American Planning Association, 60: 1* (Winter), 17-29.

Williams, H. C. W. L. (1977). On the formation of travel demand models and economic evaluation measures of user benefit. *Environment and Planning 9A:* 3, 285-344.

CHAPTER FOUR

ANATOMY OF INDUCED TRAVEL USING AN INTEGRATED LAND USE AND TRANSPORTATION MODEL

by

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Abstract:

Recent research has provided persuasive evidence for induced travel. The principle has been acknowledged by the Transportation Research Board and by the Environmental Protection Agency. This has placed renewed attention on the ability of currently available analytical tools to capture the induced travel effects of proposed new highway projects. In this study, one of the more theoretically consistent and practical integrated land use and transportation models, MEPLAN, is used to evaluate the potential importance of land use and trip distribution induced travel effects in the Sacramento, California, region. The model is used to simulate a future base case scenario (low-build) and a beltway scenario for 25- and 50-year time horizons. First, the scenarios are simulated with the full Sacramento MEPLAN model set, and its implied elasticities of vehicle miles traveled with respect to lane miles are compared to the empirical literature. The findings indicate that these elasticities compare well. Second, three sensitivity tests are performed in an attempt to isolate the contribution of different induced travel effects. The scenarios are simulated holding constant the following effects from the future base case scenario to the beltway scenario: (1) land development, (2) land development and household and employment location, and (3) land development, household and

employment location, and trip distribution. Each of these scenarios represents various methods of operating travel demand models to capture induced travel. Scenario (3) is equivalent to a travel demand model without feedback of assigned travel times to trip distribution; that is, only the mode choice and traffic assignment effects of induced travel are represented. Scenario (2) is equivalent to a travel demand model with feedback to trip distribution; that is, the trip distribution effects are added to scenario (3). Scenario (1) is equivalent to a travel demand model with feedback that is integrated with an activity allocation model; that is, the location of employment and population can vary with the scenario, but not acres of land developed. Elasticity is calculated for each sensitivity test, and the findings indicate that (3) does not account for a significant portion of induced travel, (2) accounts for approximately half, and (1) accounts for less than 20%. Third, the California vehicle emissions model is used to estimate the air quality effects of induced travel in the scenarios. Significant increases in VMT and emissions were found for the beltway scenarios run with the full MEPLAN model, and large errors were found when land use effects only were not represented and when land use and trip distribution effects were not represented.

I. Introduction

The induced travel hypothesis is grounded in economic theory and predicts that an increase in roadway supply reduces the time cost of travel, and thus (to the extent that demand is elastic) increases the quantity of travel demanded (or vehicle travel). This seemingly basic principle of induced travel has been the center of some debate between transportation planners and environmental advocates. Historically, transportation planners have asserted that the demand for travel is derived primarily from economic activities (and hence largely fixed). Environmental advocates, on the other hand, have used induced travel arguments to halt or slow proposed new highway projects. Recent research, however, has provided persuasive evidence for induced travel, and the principle has been acknowledged by leading transportation researchers (Transportation Research Board, 1995; Transportation Research Circular, 1998) and by the Environmental Protection Agency (EPA, 2000).

One of the difficulties of testing the induced travel hypothesis is controlling for confounding economic activity variables such as population, income, and other demographic trends (e.g., women in the workforce). Much of the recent induced travel research has attempted to control for these variables and has not been able to reject the hypothesis of induced travel (Goodwin, 1996; Hansen and Huang, 1997; Noland and Cowart, 2000; Chu, 2000; Fulton et al., 2000; Noland, 2000). The results of this research have yielded fairly consistent long-term elasticities of vehicle miles traveled (VMT) with respect to roadway lane miles. See Table 4.1 below.

Table 4.1. Long-term elasticities of VMT with respect to lane miles.

SOURCE	GEOGRAPHIC REGION	ELASTICITY RANGE
Hansen and Huang, 1997	County and Metropolitan area	0.3 to 0.7 (county) 0.5 to 0.9 (metropolitan)
Noland and Cowart, 2000	Metropolitan area	0.8 to 1.0
Fulton et al., 2000	County	0.5 to 0.8
Noland, 2000	State	0.7 to 1.0

The recent evidence for the induced demand hypothesis has brought renewed attention to the inability of most regional travel demand models to represent the effects of induced travel (Transportation Research Board, 1995; Transportation Research Circular, 1998). This limitation may have important implications with respect to compliance with the Clear Air Act Amendments (CAAA) and the National Environmental Policy Act (NEPA).

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

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

Most travel demand models account for mode and route shifts associated with induced travel, but many do not account for other induced travel effects such as changes in land use, trip generation (or number of trips), trip distribution (or destination choice), and departure time choice. All of the behaviors except departure time choice can change the travel models' estimates of VMT. Representation of departure time choice can change estimates of congestion if peak-spreading occurs; for example, less severe congestion would be projected during the peak period for the future base scenario, and by comparison, a highway alternative would appear less effective in reducing congestion. It is generally acknowledged that changes in mode choice, route choice, and departure time choice are effects of induced demand; however, the importance of land use, trip generation, and destination choice effects has been a source of controversy (DeCorla-Souza, 1998).

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

(Halcrow Fox and Associates, 1993). In the U.S., travel modeling studies in the Salt Lake City, Nashville, and Sacramento regions suggest that changes in trip distribution may be a significant effect of induced travel (COMSIS, 1996; Johnston and Ceerla, 1996).

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

Second, three sensitivity tests are performed in an attempt to isolate the contribution of different induced travel effects. Calibrated relationships in a model may provide some guidance about the relative magnitude of separate effects of induced travel (Coombe, 1996). The scenarios are simulated holding constant the following effects from the future base case scenario to the beltway scenario: (1) land development, (2) land development and household and employment location, and (3) land development, household and employment location, and trip distribution. Each of these scenarios represents various methods of operating travel demand models to capture induced travel. Scenario (3) is equivalent to a travel demand model without feedback of assigned travel times to trip distribution; that is, only the mode choice and traffic assignments of induced travel are represented. This is still a common method of operating travel demand models in the U.S. Scenario (2) is equivalent to a travel demand model with feedback to trip distribution; that is, the trip distribution induced travel effects are added to scenario (3). This scenario is analogous to a state-of-the-practice travel demand model. Scenario (1) is equivalent to a travel demand model with feedback that is integrated with an activity allocation model; that is, the location of employment and population can vary with the scenario, but not acres of land developed. Very few travel demand models are applied in this way in the U.S. Elasticity is calculated for each sensitivity test, and the results provide some insight into the relative contribution of land use and trip distribution effects of induced travel in the Sacramento region.

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

II. The Sacramento Region

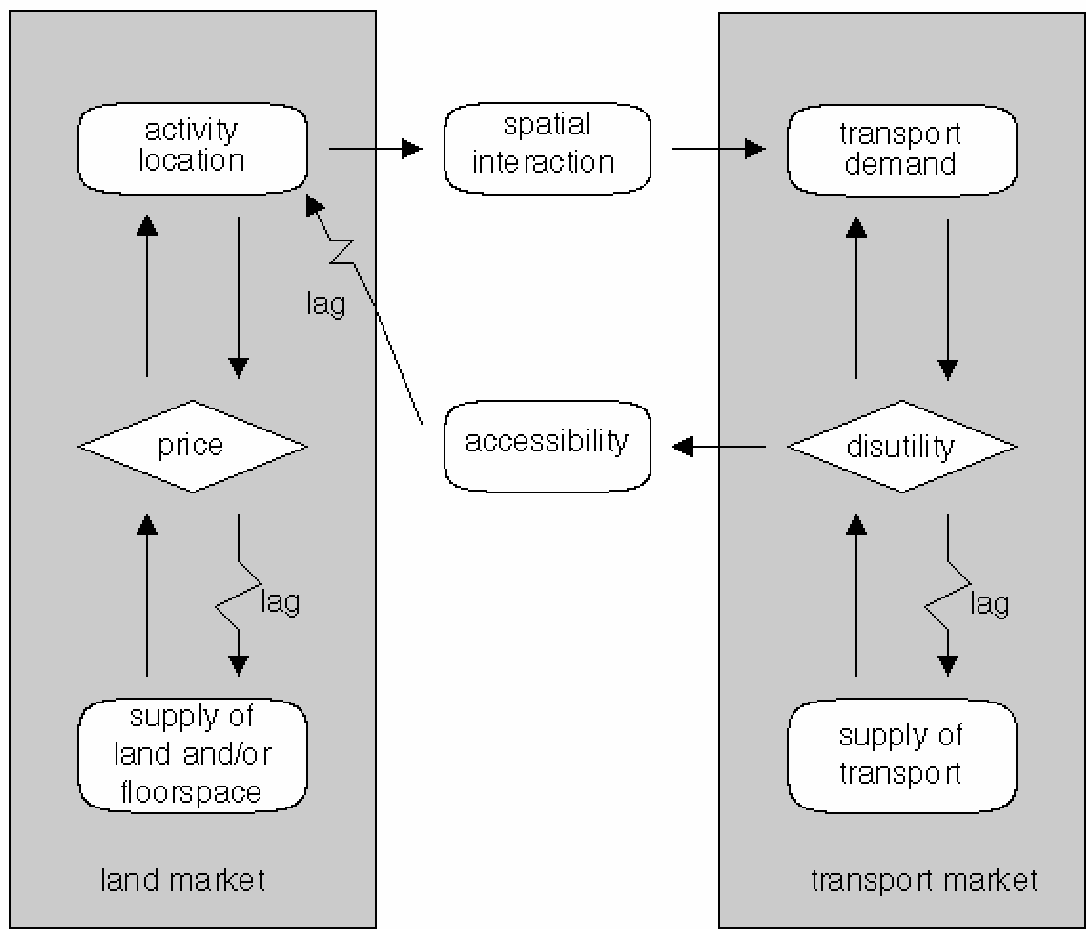
The Sacramento region is located in the central valley of Northern California. In 1995, the region was estimated to have a total population of 1.8 million and total employment of about 700,000. Population is expected to grow annually at a rate of 1.9% to 2015, and employment is expected to grow annually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

III. Methods

A. The Sacramento MEPLAN Model

The basis of the MEPLAN modeling framework is the interaction between two parallel markets, the land market and the transportation market. This interaction is illustrated in Figure 4.1. Behavior in these two markets is a response to price signals that arise from market mechanisms. In the land markets, price and generalized cost (disutility) affect production, consumption, and location decisions by activities. In the transportation markets, money and time costs of travel affect both mode and route selection decisions.

Figure 4.1. The interaction of land use and transportation markets in MEPLAN.



The cornerstone of the land market model is a spatially-disaggregated social accounting matrix (SAM) (Pyatt and Thorbecke, 1976) or input-output table (Leontieff, 1941) that is expanded to include variable technical coefficients and uses different categories of space (e.g., different types of building and/or land). Logit models (McFadden, 1974) of location choice are used to allocate volumes of activities in the different sectors of the SAM to geographic zones. The attractiveness or utility of zones is based on the cost of inputs (which include transportation costs) to the producing activity, location-specific disutilities, and the costs of transporting the resulting production to consumption activities. The resulting patterns of economic interactions among activities in different zones are used to generate origin-destination matrices of different types of trips. These matrices are loaded to a multi-modal network representation that includes nested logit forms (Williams, 1977) for the mode choice models and stochastic user equilibrium for the traffic assignment model (with capacity restraint). The resulting network times and costs affect transportation costs, which then affect the attractiveness of zones and the location of activities, and thus the feedback from transportation to land use is accomplished.

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

MEPLAN.

The specific structure of the Sacramento MEPLAN model is shown in the diagram in Figure 4.2, and Table 4.1 defines the categories in the diagram. The large matrix in the middle of the diagram lists the factors in the land use submodel and describes the nature of the interaction between factors. A given row in this matrix describes the consumption needed to produce one unit of the factor, indicating which factors are consumed and whether the rate of consumption is fixed (*f*) or price elastic (*e*).

Table 4.2. Description of categories in figure 2.

Type of Category	Category Name	Category Description
Industry and Service	AGMIN	Agriculture and mining
	MANUF	Manufacturing
	OFSRV-RES	Services and office employment consumed by households
	OFSRV-IND	Services and office employment consumed by other industry
	RETAIL	Retail
	HEALTH	Health
	EDUCATION	Primary and secondary education
	GOVT	Government
	PRIV EDU	Private education
	TRANSPORT	Commercial transportation
	WHOLESALE	Wholesale
Households	HH LOW	Households with annual income less than $20,000
	HHMID	Households with annual income between $20,000 and $50,000
	HH HIGH	Households with annual income greater than $50,000
Land Use	AGMIN LU	Land used for agriculture
	MANUF LU	Land used for manufacturing
	OFSRV LU	Land used for services and office employment
	RETAIL LU	Land used for retail
	HEALTH LU	Land used for health
	EDUCATION LU	Land used for education
	GOVT LU	Land used for government
	RES LU	Land used by residences

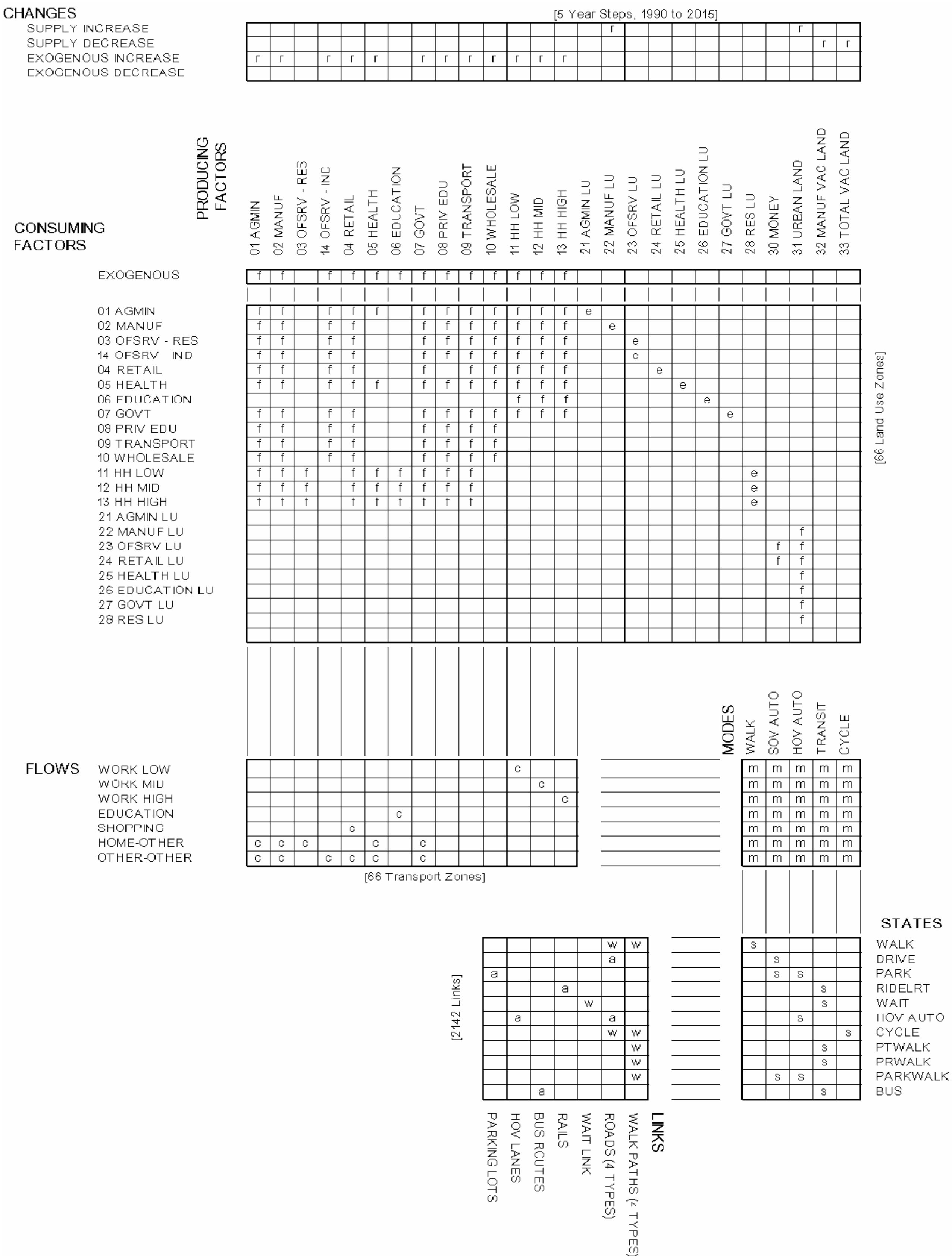


Figure 4.2. Diagram of the Sacramento MEPLAN model.

The Sacramento MEPLAN model uses eleven industry and service factors that are based on the SAM and aggregated to match employment and location data. Households are divided into three income categories (high, medium, and low) based on the SAM and residential location data. The consumption of households by businesses represents the purchase and supply of labor. The consumption of business activities by households represents the purchase of goods and services by consumers. Industry and households consume space at different rates and have different price elasticities, and thus there are seven land use factors in the model. Constraints are placed on the amount of manufacturing land use to represent zoning regulations that restrict the location of heavy industry. Each of these land uses (except agricultural land use) locates on developed land represented by the factor URBAN LAND. Two factors are used to keep track of the amount of vacant land available for different purposes in future time periods (MANUF VAC LAND and TOTAL VAC LAND), and the development process converts these two factors to URBAN LAND. The MONEY factor is a calibration parameter that allows differential rents to be paid by different users of the same category of land.

The single-row matrix just above the large matrix in Figure 4.2 shows activity that is demanded exogenously, which includes exporting industry, retired households, and unemployed households. This corresponds to the "basic" economy in the Lowry model.

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

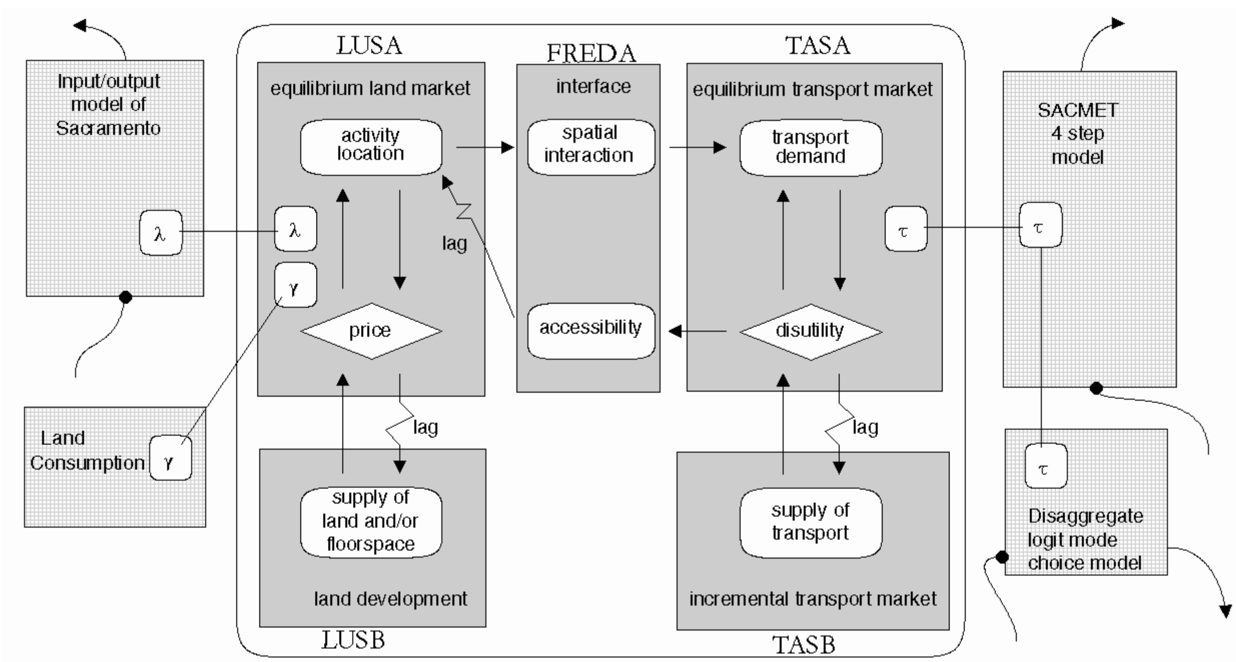
The matrix on the left below the large matrix indicates the structure of the interface between the land use and transportation submodels. Each row represents one of the matrices of transportation demand and indicates the producing factors (in the corresponding columns in the matrix above) whose matrices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

The remaining three matrices at the bottom show the structure of the transportation model. Five modes are available, and each mode can consist of several different types of activity on different types of links. The matrix directly to the right shows that all modes are available to all flows (*m*). The matrix below this, on the right, indicates the travel states (*s*) that make up each mode. The matrix on the left shows which travel states are allowed on each transportation network link and whether capacity restraint is in effect (*a*) or not (*w*). The design of the mode choice and assignment models is based on the Sacramento Regional Travel Demand model (DKS Associates, 1994). A more detailed description of the Sacramento MEPLAN model design can be found in Abraham (2000).

The parameters in the Sacramento MEPLAN model were estimated with a sequential approach in which parameters of individual submodels are estimated, and then the overall model is considered. The submodels in MEPLAN and other local models used to inform the calibration of the MEPLAN model are shown in Figure 4.3. The local models are on the left and right side of Figure 4.3. Parameters (shown as λ) were taken from the input/output economic model of Sacramento from the California Department of Water Resources and the Sacramento regional travel demand model (which uses some outside parameters in its mode choice model) for use in the Sacramento MEPLAN model.

The parameters in LUSB, TASB, and FREDA submodels were estimated separately, but the LUSA and the TASA submodels could not be estimated separately. The "spatial interaction" data at the center of the top of Figure 4.3 consists of detailed tables describing how much interaction occurs between different amounts of economic activities by type by zone. Observed data at the required level of detail were not available, and thus TASA could not be run independently of LUSA. The accessibility numbers at the center of Figure 4.3 were not available either, and thus LUSA could not be run independently of TASA. As a result, most of the parameters in both LUSA and TASA were estimated in the overall estimation process. A more detailed discussion of parameter estimation and calibration can be found in Abraham (2000).

Figure 4.3. The submodels of the Sacramento MEPLAN model and other models used to inform parameters.



B. Emissions Model

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) emissions model and the California Air Resources Board's EMFAC7F emissions factors are used in the emission analysis. The outputs from the MEPLAN model used in the emissions analysis include the results of assignment for each trip purpose by each time period (AM peak, PM peak, and off-peak). The Sacramento Area Council of Governments (SACOG) provides regional cold-start and hot-start coefficients for each hour in a twenty-four hour summer period. The 2015 emissions factors are used for the 2015 scenarios, and the 2020 emissions factors are used for the 2040 scenarios. The 2020 factors were the latest available from EMFAC7F.

IV. Scenarios

The major transportation network improvements are made in the year 2005, and thus land use is affected in the years 2010 to 2040 (in five-year increments). For the year 2015, land uses are affected in only one five-year time increment. See Figure 4.4 for a map of the scenario network. Regional population and employment totals are approximately the same across scenarios (i.e., the percentage change from the future base case is less than 1%) and income is consistent across scenarios.

Figure 4.4. Map of the Sacramento scenario network.

Base Case. The base case scenario represents a financially conservative expansion of the Sacramento region's transportation system and serves as a point of comparison for the other scenarios examined in this study. This scenario includes a relatively modest number of road-widening projects, new major roads, one highway HOV lane segment, and a limited extension of light rail.

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

Sensitivity tests of the model components that capture the induced travel effects were applied to the beltway scenario. See Table 4.3 below. The scenario was first simulated with the full MEPLAN model to represent all the induced travel effects, including land use, trip distribution, mode choice, and traffic assignment, captured by the model (Scenario A). Next, the scenario was simulated holding only acres of land developed constant from the future base scenario (Scenario B). Then, the scenario was simulated holding land development and population and employment location constant (Scenario C). This scenario is analogous to a regional travel demand model system with feedback of assigned travel times to the trip distribution step (until the model converges). In other words, the trip distribution steps are elastic with respect to changes in generalized travel costs. State-of-the-practice regional travel demand models would include these model processes. Finally, the scenario was simulated holding land development, population and employment location and trip distribution constant (Scenario D). This scenario is analogous to a regional travel demand model system without feedback of assigned travel times to trip distribution that is sensitive to changes in travel time and cost. Such a model would use fixed trip distribution matrices. Many regional travel demand models in the U.S. are still currently operated in this manner.

Table 4.3. Summary of scenarios simulated in the sensitivity analysis with the Sacramento MEPLAN model.

Scenario: Model component(s) held constant from the future base case to the beltway scenario	Description of induced travel effect captured in MEPLAN due to the highway expansion in the beltway scenario
Beltway A: None (full model simulation)	(1) Land development (2) Population & employment location (3) Trip distribution (4) Mode choice (5) Traffic assignment
Beltway B: (1) Land development	(2) Population & employment (3) Trip distribution (4) Mode choice (5) Traffic assignment
Beltway C: (1) Land development (2) Population & employment location	(3) Trip distribution (4) Mode choice (5) Traffic assignment
Beltway D: (1) Land development (2) Population & employment location (3) Trip Distribution	(4) Mode choice (5) Traffic assignment

V. Results

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

A. Land Use

Table 4.4 presents the household and employment land use results by superzone for the year 2015 and 2040. In the Base Case scenario, land development from 1990 to 2015 and 2040 occurs north, east, and south of the City of Sacramento. There is limited land development in Yolo County because of exclusive agricultural zoning in the county. Over time for both the 2015 and 2040 time horizons, households and employment tend to locate primarily in existing, built-up areas northeast, east, and immediately south of the central business district (CBD). In 2040, however, households are more likely to locate in relatively more remote sections of these areas (e.g., South Sutter, Southeast Sacramento County, and El Dorado Hills). In general, household and employment location tends to follow land development; however, density increases in some zones. The land use results for the other scenarios are discussed in comparison to the future base case scenarios.

Table 4.4. Percentage change from the base case scenario to the beltway scenario by superzone.

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

Roadway expansion in the beltway scenario allows industry to locate further away from the households that it serves and employs. Employment location is more intense in the existing, built-up areas northeast, east, and immediately south of the CBD, and in the CBD for both the 2015 and 2040 time horizons. Differences in employment location, however, are more dramatic in 2015 than in 2040, and the opposite is true for households. In 2015 there is a movement of households further away from employment compared to the base case; however, this shift is more intense by 2040, as more households locate in the most remote eastern sections of the region.

Businesses are moved around more easily than households in the Sacramento MEPLAN model in the shorter term. First, the model allows businesses in the presence of higher rents to use less space. Second, the model does not include a floorspace submodel, and thus differences among types of commercial buildings cannot be distinguished and there is no cost to redevelop a building space. As a result, it is relatively easy for the model to show retail operations to moving into a former warehouse or an office moving into a former retail space. A floorspace model would better simulate the difficulty of such moves by distinguishing among building types and representing the time and money needed to redevelop buildings for new use.

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

B. Travel

The daily VMT results for the sensitivity analysis of the beltway scenario are provided in Table 4.5. The beltway scenario simulated with the full MEPLAN model (Scenario A) generates a relatively large increase in VMT compared to the base case, and this increase grows over time (13% in 2015 and 18% in 2040). Greater distances between the home and the workplace and faster auto travel times that result from roadway construction in the beltway scenario increase VMT. The error resulting from the failure to simulate the various induced travel effects in MEPLAN (see figures in parentheses in Table 4.5) is, in most cases, significant and this error increases over time.

Note that a result is determined to be significant when the error due to the failure to represent the induced travel effect is as great or greater than the percentage change from the base case to the alternative scenarios, in which the effect was not represented. In Scenario D, when only the mode choice and traffic assignment effects of induced travel are represented, MEPLAN predicts a small reduction in VMT because of the HOV lanes in the beltway network. In Scenario C, when the trip distribution effects of induced travel are added, the model captures approximately half of the increase in VMT found in Scenario A. Comparing Scenario C to Scenario B indicates that population and employment changes also make a significant contribution to induced travel in MEPLAN. Comparing Scenario B to Scenario A indicates that, when only land development is held constant from the future base case scenario, the error is small (1% to 2%) compared to other beltway scenarios (Scenarios C to D). Thus, changes in acres developed make a relatively smaller contribution to induced travel than do changes in employment and population location.

Table 4.5. Daily VMT results for the Sacramento Region.

Scenarios: model component(s) allowed to vary from the future base case scenario	2015 percentage change VMT	2040 percentage change VMT
Scenario A: (1) Land development (2) Population & employment location (3) Trip distribution (4) Mode choice (5) Traffic assignment	13%	18%
Scenario B: (2) Population & employment location (3) Trip distribution (4) Mode choice (5) Traffic assignment	11% (-2%) [a]	17% (-1%)
Scenario C: (3) Trip distribution (4) Mode choice (5) Traffic assignment	6% (-6%)	10% (-7%)
Scenario D: (4) Mode choice (5) Traffic assignment	0% (-12%)	-1% (-16%)

[a] Figures in parentheses are percentage change in VMT from Scenario A.

The results of the elasticity of VMT with respect to lane miles for the sensitivity tests are presented in Table 4.6. Elasticity of VMT with respect to lane miles is calculated as the percentage change in VMT from the base case scenario to an alternative Beltway scenario (i.e., Scenarios A to D), divided by the percentage change in total lane miles from the base case scenario to an alternative Beltway scenario (i.e., Scenarios A to D). The elasticity results for Scenario A, in which the full model was run, compare well to the empirical elasticity results from aggregate studies at the metropolitan level described above (0.8 for 2015 and 1.1 for 2040). The very long-term elasticity for the year 2040 is somewhat higher than that found in the empirical literature. Elasticity tends to increase over time as expected. The elasticity is zero when the MEPLAN model simulates only the mode choice and traffic assignment effects of induced demand (Scenario D). Again, this is because of the HOV lanes in the beltway network. When the trip distribution effects are added (Scenario C), approximately half of the induced travel effects are captured. Comparing Scenario C to Scenario B indicates that changes in population and employment location account, approximately, for the other half of the induced travel effects. Comparing Scenario B to Scenario A indicates that the failure to represent changes in acres of land development accounts for a relatively smaller portion of the elasticity compared to the location of employment and households.

Table 4.6. Elasticity of VMT with respect to lane miles results for the Sacramento Region.

Scenarios: model component(s) held constant from the future base case scenario	2015 Elasticities	2040 Elasticities
Scenario A: (1) Land development (2) Population & employment location (3) Trip distribution (4) Mode choice (5) Traffic assignment	0.8	1.1
Scenario B: (2) Population & employment location (3) Trip distribution (4) Mode choice (5) Traffic assignment	0.6 (-16%) [a]	1.0 (-1%)
Scenario C: (3) Trip distribution (4) Mode choice (5) Traffic assignment	0.4 (-54%)	0.6 (-43%)
Scenario D: (4) Mode choice (5) Traffic assignment	0.0 (-100%)	0.0 (-100%)

[a] Figures in parentheses are the percentage changes in the Scenarios B, C, and D elasticities from Scenario A.

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

The similarities of the elasticity results in this disaggregate study with the elasticity results from the aggregate studies (described in Table 4.1) increases the confidence that the results in this study and the aggregate studies are reasonable. One of the critiques of the empirical induced travel studies has been that they use aggregate data as opposed to disaggregate data.

C. Vehicle Emissions

The daily vehicle emissions results are presented in Table 4.7. When the full MEPLAN model is used to simulate the beltway scenario (Scenario A), there is a significant increase in emissions (ranging from 6% to 16%). However, when the induced travel effects of only mode choice and traffic assignment are represented in the MEPLAN model (Scenario D), emissions decrease (ranging from 1% to 9%) because of the reduction in VMT resulting from the HOV lanes in the beltway scenario. When the induced travel effects of trip distribution are added (Scenario C), emissions are largely predicted to increase, but the increase is generally less than half that obtained from Scenario A. Some pollutants are reduced in Scenario C because of increased speeds, and thus reduced vehicle hours of travel. The errors due to the failure to represent the induced travel effects of land use are significant in scenarios C and D. Again, when acres of land developed are held constant, the errors are comparatively less significant than errors from changes in employment and population location. In general, emissions increase, but the error due to the failure to represent the induced travel effects is relatively stable over time.

Table 4.7. Daily vehicle emissions results for the Sacramento Region.

Scenarios	2015				2040			
	TOG	CO	NOx	PM	TOG	CO	NOx	PM
Scenario A	10%	12%	12%	8%	9%	13%	16%	6%
Scenario B	7% (-3%) [a]	10% (-2%)	10% (-2%)	5% (-3%)	7% (-2%)	11% (-1%)	15% (-1%)	4% (-1%)
Scenario C	1% (-9%)	4% (-7%)	6% (-6%)	-4% (-11%)	-3% (-11%)	4% (-8%)	10% (-5%)	-5% (-10%)
Scenario D	-5% (-13%)	-2% (-13%)	-1% (-12%)	-8% (-14%)	-7% (-15%)	-4% (-8%)	-1% (-15%)	-9% (-14%)

[a] Figures in parentheses are percentage change in tons of emissions from Scenario A.

VIII. Summary and Conclusions

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

First, the scenarios were simulated with the full Sacramento MEPLAN model set and its implied elasticities of VMT with respect to lane miles were compared to the empirical literature. This scenario includes changes in land use (acres of land developed and employment and population location), trip distribution, mode choice, and traffic assignment. Very few regions in the U.S. analyze all these induced travel effects of proposed highway projects. The calculated elasticity for the beltway scenario was 0.8 in

2015 and 1.1 in 2040. These elasticities compare reasonably well to elasticities reported in the empirical literature, which range from 0.5 to 1.0 for metropolitan regions. The similarities of the elasticity results in this disaggregate study with the elasticity results from the aggregate studies (described in Table 4.1) increases the confidence that the results in this study and the aggregate studies are reasonable. One of the critiques of the empirical induced travel studies has been that they use aggregate data as opposed to disaggregate data.

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

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

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

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

Finally, the California vehicle emissions model (DTIM2 with EMFAC7F emissions factors) was used to estimate the air quality effects of induced travel in the simulated scenarios. When the full MEPLAN model was used to simulate the beltway scenario, it was found to significantly increase VMT (13% in 2015 and 18% in 2040) and emissions (approximately 11% in both time horizons). When the land use effects only were not represented and the land use and trip distribution effects were not represented, large errors were found for the estimates of VMT (6% to 16%) and emissions (8% to 13%) and, in the latter case, the rank ordering of the scenarios was altered. When origins and destinations are held constant, emissions are projected to decrease for all pollutants compared to the base case scenario because of travel time and distance saved resulting from more direct available routes to destinations (provided by the new highway capacity).

The results of the study indicate that the induced travel effects represented by the Sacramento MEPLAN model (and not typically represented by regional travel demand models) make a significant contribution to projections of VMT and emissions. The error that results from the failure to represent the induced travel effects is in many cases as large as or larger than the percentage change of the scenarios from the future base case. The magnitude of change between the scenario and the base case is significantly altered.

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

REFRENCES

Abraham, J. E. (2000). Parameter Esimation in Urban Models: Theory and Application to a Land Use Transport Interaction Model of the Sacramento, California Region. Diss., University of Calgary, Canada.

Chu, X. (2000). Highway Capacity and Areawide Congestion. Preprint for the 79th Annual Meeting of the Transportation Research Board. National Research Council, Washington, D.C.

COMSIS Corporation (1996). Incorporating Feedback in Travel Forecasting: Methods, Pitfalls and Common Concerns. Office of Environmental Planning, Federal Highway Administration, DOT-T-96-14, Washington, D.C.

Coombe, D. (1996). Induced traffic: what do transportation models tell us? *Transportation*, *23,* 83-101.

Council on Environmental Quality (1987). Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act, 40 CFR parts 1500-1508.

DeCorla-Souza, P. and H. Cohen (1998). Accounting for Induced Travel in Evaluation of Metropolitan Highway Expansion. Preprint for the 77th Annual Meeting of the Transportation Research Board. National Research Council, Washington, D.C.

DKS Associates (1994). Model Development and User Reference Report. Sacramento Area Council of Governments, Sacramento, CA, October.

Dowling R.C. and S. B. Colman (1998). In Transportation Research Circular. *Highway Capacity Expansion and Induced Travel: Evidence and Implications*. Transportation Research Board. National Research Council. *481* (February), 21-32.

Halcrow Fox and Associates (1993). *Review and Specifications of Model Elasticities*. Report for the Department of Transport by Halcrow Fox and Associates, Accent Marketing & Research, and the University of Leeds, as part of the London Congestion Charging Research Programme.

Hunt J. D., and M. H. Echenique (1993). Experiences in the application of the MEPLAN framework for land use and transportation interaction modeling. Proceedings of the 4th National Conference on the Application of Transportation Planning Methods, Daytona Beach, Florida, USA, (May), 723-754.

Hunt, J. D. (1994). Calibrating the Naples land use and transport model. *Environment and Planning 21B*, 569-590.

Fulton, L. M., D. J. Meszler, R. B. Noland, and J. V. Thomas (2000). A Statistical Analysis of Induced Effects in the U.S. Mid-Atlantic Region. Preprint for the 79th Annual

Meeting of the Transportation Research Board. National Research Council, Washington, D.C.

Goodwin, P. B. (1996). Empirical evidence of induced traffic, a review and synthesis, *Transportation*, *23*, 35-54.

Hansen, M. and Y. Huang (1997). Road supply and traffic in California urban areas, *Transportation Research A*, *31*, 205-218.

Leontief, W. (1941). *The Structure of the American Economy 1919-1939*, Oxford University Press, New York, NY, USA.

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In *Frontiers in Econometrics*, Editor: Zaraembka P. Academic Press, New York, USA, 105-142.

Meyer, M. D., and E. J. Miller (1984). *Urban Transportation Planning: A Decision-Oriented Approach*. McGraw-Hill, New York, USA.

Noland, R. B. (2000). Relationships between highway capacity and induced vehicle travel. *Transportation Research A* (forthcoming).

Noland, R. B. and W. A. Cowart (2000). Analysis of Metropolitan Highway Capacity and the Growth in Vehicle Miles of Travel. Preprint for the 79th Annual Meeting of the Transportation Research Board. National Research Council, Washington, D.C.

Pyatt, G., and E. Thorbeck (1976). *Planning Techniques for a Better Future*. International Labour Office, Geneva, Switzerland.

Sacramento Area Council of Governments (1996). 1995 Regional Housing, Population, and Employment Projections. Sacramento, CA.

Transportation Research Board (1995). *Expanding metropolitan highways: implications for air quality and energy use*, Special report 245, National Research Council, National Academy Press, Washington, D.C.

Transportation Research Circular (1998). *Highway Capacity Expansion and Induced Travel: Evidence and Implications*. Transportation Research Board. National Research Council. *481* (February).

U.S. Environmental Protection Agency (2000). Induced Travel: A Review of Recent Literature with a Discussion of Policy Issues. Office of Policy. Energy and Transportation Sectors Division, Washington, D.C.

Williams, H. C. W. L. (1977). On the formation of travel demand models and economic evaluation measures of user benefit. *Environment and Planning 9A: 3*, 285-344.

CHAPTER FIVE

HEURISTIC POLICY ANALYSIS OF REGIONAL LAND USE, TRANSIT, AND TRAVEL PRICING SCENARIOS USING TWO URBAN MODELS

by

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Abstract:

To address some of the uncertainties inherent in large-scale models, two very different urban models, an advanced travel demand model and an integrated land use and transportation model, are applied to evaluate land use, transit, and auto pricing policies in the Sacramento, California, region. The empirical and modeling literature is reviewed to identify effective land use, transit, and pricing policies and optimal combinations of those policies and to provide a comparative context for the results of the simulation. This study illustrates several advantages of this approach to addressing uncertainty in large-scale models. First, as Alonso (1968) asserts, the intersection of two uncertain models produces more robust results than one grand model. Second, the process of operationalizing policy sets exemplifies the theoretical and structural differences in the models. Third, a comparison of the results from multiple models illustrates the implications of the respective models' strengths and weaknesses and may provide some insights into heuristic policy strategies. Some of the key findings in this study are (1) land use and transit policies may reduce VMT and emissions by about 5% to 7%, and the addition of modest auto pricing policies may increase the reduction by about 4% to 6%

compared to a future base case scenario for a 20-year time horizon; (2) development taxes and land subsidy policies may not be sufficient to generate effective transit-oriented land uses without strict growth controls elsewhere in the region; (3) parking pricing should not be imposed in areas served by light rail lines and in areas in which increased densities are promoted with land subsidy policies.

I. Introduction

It is well known that the predictive accuracy of large-scale urban models is less than desired. Just some of the reasons for this include incomplete theory and poor data. However, models are our primary tools for understanding the behavior of large, complete systems; they summarize our understanding of the system and allow this understanding to be subjected to critical evaluation. Models allow us to identify causal relationships and to forecast the future and thus offer the hope that we can take steps now to avoid harmful effects in the future.

As Morgan and Henrion (1990) assert, the best use of large-scale models in policy analysis “should not be prediction but, rather, insight that can guide the development of heuristic policy strategy.” Uncertain models should not be used to identify the best answer but rather to “help the decision maker to identify and explore possible alternatives as well as to choose among them.”

William Alonso (1968) has suggested that one of the best ways to deal with uncertainty and minimize error in large-scale models is to build several models that use available data. If the errors are in different directions and the average is taken, then the errors would tend to cancel. He states that “the strategy is not to build one master model of the real world, but rather a set of weak models as alternative models for the same set of phenomena" and that "their intersection will produce 'robust theorems'."

To address some of the uncertainties inherent in large-scale models, two very different urban models, an advanced travel demand model and an integrated land use and transportation model, are applied to evaluate land use, transit, and auto pricing policies in the Sacramento, California, region. The empirical and modeling literature is reviewed to identify effective land use, transit, and pricing policies and optimal combinations of those policies and to provide a comparative context for the results of the simulation. Travel demand models are routinely applied in the U.S. for transportation and air quality studies. This is one of the first applications of an integrated land use and transportation model in the U.S.; however, such models have been applied throughout the world for over 20 years. This study illustrates several advantages of this approach to addressing uncertainty in large-scale models.

First, as Alonso (1968) asserts, the intersection of two uncertain models produces more robust results than one grand model. If multiple models that represent different theoretical and structural constructs of the system and have different strengths and weaknesses reach some agreement on the relative effectiveness of the simulated policies, then the result is more persuasive. However, it is possible that models may be biased in the same direction and in this case errors will not cancel.

Second, because each urban model is a different theoretical and structural construct of the system, the policies of interest must be operationalized differently in the models. For example, in the travel demand model, we must take a command and control approach to implement land use policies, but we can represent fine geographic detail of the policies. In the integrated urban model, however, we can explore market mechanisms to implement those policies, but we cannot represent fine geographic detail. In general, the process of operationalizing the policy sets exemplifies the theoretical and structural differences in the models, in other words, what aspect of the policy can be represented and what aspect must be ignored. Given the broad application of the much criticized four-step travel demand models in the U.S. and the current interest in integrated land use and transportation models, such an example is important.

Third, a comparison of the results from multiple models illustrates the implications of the respective models' strengths and weaknesses and may provide some insights into heuristic policy strategies. For example, how effective are land use measures implemented with command and control mechanisms rather than market mechanisms? Is the sum of the policies examined in a scenario greater or less than the sum of the effect of each individual policy? How well does each model capture potential synergistic effects? Answers to these questions would suggest the formulation of new and more effective policy sets.

II. Literature Review

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

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

However, Ewing (1997) concludes just the opposite, that is, that high-density development reduces VMT and energy consumption. Ewing asserts that Gordon and Richardson use the wrong land use variable; accessibility is significant, not density. He finds that "households living in the most accessible location spent about 40 minutes less per day traveling by vehicle than do households living in the least accessible locations (Ewing et al., 1994; Ewing 1995)." He also challenges Gordon and Richardson's use of macro travel statistics to make conclusions about micro travel behavior. He cites recent studies that use micro level travel data and come to very different conclusions from Gordon and Richardson (e.g., Kitamura et al., 1995 and Ewing, 1996).

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

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

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

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

A. Empirical Studies

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

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

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

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

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

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

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

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

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

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

B. Modeling Studies

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

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

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

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

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

Studies in the Sacramento region also show that density policies can be effective. One study uses a fully equilibrated travel model and shows reductions in VMT by 10%, fuel by 14%, and emissions by 8% to14% over 20 years when land use intensification policies around light rail stations are combined with auto pricing policies and expanded transit (Johnston and Ceerla, 1995). In another study, a similar scenario (but without pricing policies) uses an advanced travel model and finds that VMT is reduced by 4% and emissions by 3% to 5% compared to the no build scenario (Rodier and Johnston, 1997).

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

1. auto ownership rates 5% lower than in the No Build alternative;
2. fewer work trips by single occupancy vehicle than in the No Build alternative (58% compared to 76% for the No Build alternative);
3. more than twice as many work trips by transit as the Highways Only and No build alternatives;
4. fewer vehicle trips per household each day (7.17 compared to 7.53 for the No Build alternative);
5. less peak hour traffic delay than the No Build or Highways Only alternatives;
6. fewer vehicle miles of travel than the No Build or the Highway alternatives (7.9% fewer than the Highways Only alternative);
7. fewer peak hour vehicle hours of travel (10.7% fewer than the Highways Only alternative);.
8. reductions in nitrogen oxide, hydrocarbons, and carbon monoxide emissions of 2.6% to 6.7% compared to the No Build alternative; and
9. reductions in greenhouse gas emissions and energy consumption of about 6.4% compared, again, to the No Build alternative. (Cambridge Systematics Inc et al., 1996)

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

1. about 35% of TOD households would choose to own only one car, and 9% would own none;
2. nearly 30% of residents would travel to work by transit;
3. TOD residents would be twice as likely to walk or bike to work as residents of the study area in the Highway Only alternative;
4. Children in TODs would be twice as likely to walk or bike to school as children in the study area in the Highways Only alternative; and
5. TOD households would need to make about 1.7 fewer car trips per day than households in the study area in the Highways Only alternative. (Cambridge Systematics Inc et al., 1996)

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

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

C. Conclusions

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

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

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

III. Methods

A. An Integrated Land Use and Transportation Model: MEPLAN

From the mid-1960s to the late 1970s, research in the Martin Centre at Cambridge University, England produced a family of interactive land use and transportation models known as the Martin Centre Model (Simmonds, 1995). One of the models developed from this structure is Marcial Echenique's software package known as MEPLAN (Echenique, 1994).

The MEPLAN model integrates three economic models: (1) an input-output or social accounting model, (2) a random utility model of location choice integrated with the social accounting model in a way that is similar to, but more general than, Lowry's 1961 model, and (3) a rent-density function based on Alonso's 1964 theory of urban land markets or bid-rent theory (Simmonds, 1995). The input-output model uses exogenous basic demand in each time period to generate endogenous economic activities (population and non-basic employment). The random utility model of location choice spatially allocates basic employment, residents, and non-basic employment in a series of iterations until the land markets equilibrate. The result is the estimation of the amount and location of population and employment, land use, rents, and flows of economic activities between locations (e.g., from home to work). These flows are then transformed into person trips and truck movements between origin-destination pairs.

The model is "quasi-dynamic" in that the time and monetary costs of travel from the transportation model are fed back to the land use model in the next time period. In addition, the amount of development in each zone between time periods is a function of the prices and arrangement of activities in the previous time period. Abraham (2000) describes in detail the calibration and structure of the Sacramento MEPLAN model.

The Sacramento MEPLAN model has been developed as part of a larger project to compare alternative land use models on a consistent basis in the U.S. The MEPLAN framework draws on over 25 years of spatial economic modeling experience and has been used around the world (Hunt and Echenique, 1993), but the Sacramento model is the first application in the U.S. Moreover, this is the first study in which an integrated land use and transportation model uses separate AM, PM, and off-peak assignment models (as opposed to an average daily assignment model) for more accurate emissions analysis.

B. An Urban Transportation Planning Model: SACMET96

The standard Urban Transportation Planning (UTP) model was developed in the late 1960s and early 1970s to support large-scale regional transportation studies in the U.S. and to determine the need for additional roadway lanes or segments to relieve traffic congestion. Advanced versions of the UTP model have adapted it to better address air quality problems by improving the models' representation of congestion, travel modes, auto ownership, land use variables, and time and cost variables. These models also draw on discrete choice theory to explain travel behavior. The 1996 Sacramento regional travel demand model (SACMET96) is a prime example of a UTP model that has been adapted to address current regional mobility and air quality issues.

DKS Associates developed the SACMET96 model for the Sacramento Regional Council of Governments (SACOG) with a 1991-travel behavior survey conducted in the region (DKS, 1994). The model makes use of over one thousand travel analysis zones. Some of the key features of the model include: (1) model feedback of assigned travel impedances to the trip distribution step; (2) auto ownership and trip generation steps with accessibility variables; (3) a joint destination and mode choice model for work trips; (4) a mode choice model with separate walk and bike modes, walk and drive transit access modes, and two carpool modes (two and three or more occupants); (5) land use, travel time and monetary costs, and household attribute variables included in the mode choice models; (6) all mode choice equations in logit form; and (7) a trip assignment step that assigns separate A.M., P.M., and off-peak periods.

C. Emissions Model

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) and the California Air Resources Board's EMFAC7F model are used in the emissions analysis. The outputs from the travel demand model used in the emissions analysis include the results of the assignment for each trip purpose by each time period (A.M. peak, P.M. peak, and off-peak). The Sacramento Area Council of Goverments (SACOG) provides regional coldstart and hotstart coefficients for each hour in a twenty-four hour summer period.

IV. Scenarios

The scenario descriptions apply to the scenarios modeled by both MEPLAN and SACMET96 except when differences are identified. All the transportation network improvements are made in the year 2005 for the MEPLAN scenarios, and thus land uses are affected in only one of the five-year time increments used in the model.

Base Case. The base case scenario represents a financially conservative expansion of the Sacramento region's transportation system and serves as a point of comparison for the other scenarios examined in this study. This scenario includes a relatively modest number of road-widening projects, new major roads, one freeway HOV lane segment, and a limited extension of light rail.

Pricing & Light Rail. In the both the SACMET96 and MEPLAN scenarios, approximately 75 new track miles of light rail are added to the transportation network and auto-pricing policies are also imposed. These pricing policies include a 30% increase in the operating cost of private vehicles (to simulate a gas tax) and a CBD parking tax representing an average surcharge of $4 for work trips and $1 for other trips. Figure 5.1 illustrates the light rail network.

Figure 5.1. Map of the Sacramento scenario network.

Transit Oriented Development (TOD), Light Rail & Advanced Transit. The increased densities in the TOD scenarios were modeled differently in MEPLAN than in SACMET96. The method of simulation in each model illustrates some of their respective strengths and weaknesses. Both scenarios include the light rail network described above but not the auto pricing policies.

The MEPLAN model is theoretically comprehensive, representing land markets with endogenous prices and market clearing in each period. As a result, MEPLAN can simulate such policies as, for example, the release of zoning density caps near to rail stations, tax benefits for infill development, and land development fees on raw-land projects near the urban edge. In this MEPLAN simulation, increased densities in the TODs are achieved through land subsidies of 5% of expenditures in the year 2000 on land rent in the TOD zones. The subsidies are offset by 30% land rent surcharges in other zones so that region-wide the effect is revenue neutral. Note that MEPLAN has only 57 zones.

SACMET96 does not have a land use model and thus cannot simulate large-scale land use policies such as land subsidies and taxes. However, SACMET96 has many small zones (1077), detailed travel networks, and includes zone-based walk and bike accessibility variables. Thus, in the SACMET96 simulation, increased densities in the TODs are achieved by manually adjusting zonal land use. TODs were located around 79 light rail stations and have an average density of 15 households per acre, 10 retail employees per acre, and 20 non-retail employees per acre. These density levels were developed based on a review of current land use densities in Sacramento areas that are considered to be TOD prototypes. To achieve the TOD densities, growth in households

(147,917), retail employment (40,505), and non-retail employment (135,768) from 1995 to 2015 in the outer zones (farther than 1 mile from the light rail lines) are moved to the zones in the TODs. The ratios of the household classifications are held constant in all zones, and thus only the total number of households is changed in zones. School enrollments are also adjusted to correspond to the changes in households. To reflect the improved walk and bike environment of the TODs, the pedestrian environment factors are increased.

In general, the TOD densities in SACMET96 are greater than in MEPLAN. This is because the MEPLAN simulation could not match the SACMET96 TOD densities with a reasonable subsidy and taxation policy. Table 5.1 provides total household and employment by zone. Household and employment figures from the SACMET96 zones are aggregated to MEPLAN zones.

Table 5.1. 2015 change in households and employment in TOD zones from the Base Case.

	HOUSEHOLDS			EMPLOYMENT		
Zone	SACMET	MEPLAN TOD	MEPLAN with Pricing	SACMET	MEPLAN TOD	MEPLAN with pricing
1. North Natomas	5,717	1,498	747	7,432	1,721	208
3. North Highlands	12,641	5,769	2,365	16,434	5,589	7,029
4. Citrus Heights	1,470	7,713	3,905	1,910	3,944	1,272
6. Folsom	12,955	13,387	6,869	16,842	9,870	8,596
7. South Natomas	7,478	7,662	3,422	9,476	10,585	10,540
8. North Sacramento	10,106	6,231	1,454	12,521	16,993	22,908
11. Fair Oaks	2,071	4,445	2,185	2,693	681	705
12. Rancho Cordova	13,594	29,403	10,718	18,675	15,356	15,943
13. Downtown	33,394	1,483	3,367	19,604	4,297	-25,767
14. Parkpocket	10,249	9,234	5,133	12,914	6,990	6,169
15. East Sacramento	12,390	8,176	2,182	16,093	14,862	12,506
16. South Sacramento	6,547	11,158	6,228	8,511	9,652	6,096
19. Elk Grove	8,368	9,446	4,546	10,879	8,395	6,484
25. Antelope	353	3,247	1,603	459	2,165	1,282
50. West Sacramento	6,016	6,935	3,469	9,802	8,006	6,927
70. Roseville	9,258	21,447	10,492	12,031	29,850	19,593
Total	152,609	147,233	68,683	176,274	148,954	100,492

In the TOD, Light Rail & Advanced Transit scenario, transit frequencies in the light rail network are doubled, and advanced transit information systems (ATIS) and local paratransit service are added. In MEPLAN, the value of wait time is reduced by a factor of three to represent ATIS, and the access time to transit in the TOD zone is reduced by 3 minutes to represent paratransit service. In SACMET96, the maximum initial wait times for all transit service is reduced to 5 minutes to represent ATIS and paratransit service is simulated by adding new bus only routes with short direct routes between TOD zones in the transit network.

Pricing, TOD, Light Rail & Advanced Transit. This scenario includes the TOD scenarios described above for the respective models and the pricing policies from the Pricing & Light Rail scenario.

V. MEPLAN Results

A. Land Use

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

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

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

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

B. Travel Results

In the Pricing & Light Rail scenario, there is an increase in mobility over short distances in central zones where light rail service is very good compared to the Base Case. The MEPLAN daily mode share results for the 2015 time horizon are presented in Table 5.2. The greater separation of home and work, the availability of high quality rail service, and the increase in auto operating costs serve to increase transit mode share significantly and to reduce drive alone mode share. There is an increase in the shared ride mode share in this scenario (even greater than in the HOV lane scenario) because ride sharing allows the cost of travel to be shared. The walk and bike mode share also increases. The mode shifts produce a decrease in auto trips, a significant decrease in VMT, and a slight increase in mean travel speed compared to the Base Case scenario. The MEPLAN daily vehicle travel results for the 2015 time horizon are presented in Table 5.3.

Table 5.2. 2015 MEPLAN scenarios: percentage change in mode share from the Base Case.

SCENARIOS	DRIVE ALONE	SHARED RIDE	TRANSIT	WALK & BIKE
Pricing & Light Rail	-6.8%	6.0%	15.0%	4.7%
TOD, Light Rail & Advanced Transit	-11.6%	-0.6%	376.4%	4.3%
Pricing, TOD, Light Rail & Advanced Transit	-11.8%	-0.3%	374.3%	4.3%

Table 5.3. 2015 MEPLAN scenarios: percentage change in daily vehicle travel[a] from the Base Case.

SCENARIOS	TRIPS	MILES TRAVELED	MEAN TRAVEL SPEED
Pricing & Light Rail	-2.8%	-6.8%	0.3%
TOD, Light Rail & Advanced Transit	-9.1%	-4.8%	1.2%
Pricing, TOD, Light Rail & Advanced Transit	-9.5%	-10.0%	2.2%

[a] Vehicle travel includes drive alone and HOV mode only.

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

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

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

C. Emissions

In general, the MEPLAN emissions results follow the travel results described above. The Pricing, TOD, Light Rail & Advanced Transit scenario provides the greatest decrease in emissions compared to the Base Case scenario, followed by the Pricing & Light Rail scenario, and finally the TOD, Light Rail & Advanced Transit scenario. Note, however, that the emissions reduction are relatively similar for the Pricing & Light Rail scenario and TOD, Light Rail & Advanced Transit scenario and that the PM result is lower in the TOD, Light Rail & Advanced Transit scenario than in the Pricing & Light Rail scenario. The daily emissions results for the MEPLAN scenarios are presented in Table 5.4.

Table 5.4. 2015 MEPLAN scenarios: percentage change in daily emissions from the Base Case.

SCENARIOS	TOG	CO	NO_X	PM
Pricing & Light Rail	-9.2%	-8.1%	-7.0%	-9.8%
TOD, Light Rail & Advanced Transit	-8.6%	-7.2%	-4.6%	-10.9%
Pricing, TOD, Light Rail & Advanced Transit	-15.4%	-12.7%	-9.9%	-16.8%

VI. Comparison of MEPLAN Results to SACMET96 Results

The mode share, daily vehicle travel, and emissions projections for the SACMET96 scenarios are presented in Tables 5.5 to 5.7. As described above, the scenarios simulated in SACMET96 are somewhat different from the scenarios simulated in MEPLAN. In general, the TODs in the SACMET96 scenarios have a much greater intensity of household and employment location than in the TODs in the MEPLAN scenarios (see Table 5.1 described above).

Table 5.5. 2015 SACMET96 scenarios: percentage change in daily mode share from the Base Case.

SCENARIOS	DRIVE ALONE	SHARED RIDE	TRANSIT	WALK & BIKE
Pricing & Light Rail	-0.4%	-0.2%	22.1%	1.8%
TOD, Light Rail & Advanced Transit	-3.3%	-2.3%	168.6%	18.1%
Pricing, TOD, Light Rail & Advanced Transit	-4.3%	-1.9%	195.2%	20.1%

Table 5.6. 2015 SACMET96 scenarios: percentage change in daily vehicle travel[a] from the Base Case.

SCENARIOS	TRIPS	VEHICLE MILES TRAVELED	MEAN TRAVEL SPEED
Pricing & Light Rail	-0.4%	-0.6%	0.3%
TOD, Light Rail & Advanced Transit	-0.8%	-6.5%	-0.3%
Pricing, TOD, Light Rail & Advanced Transit	-2.2%	-8.8%	1.5%

[a] Vehicle travel includes drive alone and HOV mode only.

Table 5.7. 2015 SACMET96 scenarios: percentage change in daily emissions from the Base Case.

SCENARIOS	TOG	CO	NO_X	PM
Pricing & Light Rail	-0.4%	-0.4%	-0.4%	-0.4%
TOD, Light Rail & Advanced Transit	-5.6%	-5.5%	-6.5%	-7.0%
Pricing, TOD, Light Rail & Advanced Transit	-7.7%	-7.1%	-8.1%	-9.8%

The rank ordering of the scenarios with respect to travel and emissions results would probably not be altered between the MEPLAN and SACMET96 models for comparable scenarios. Since the scenarios do differ between the two models, however, some changes in rank ordering are seen. The intensity of the land uses is greater in the SACMET96 TODs than in the MEPLAN TODs. As a result, the Pricing & Light rail scenario is superior to the TOD, Light Rail, & Advanced Transit scenario in the MEPLAN simulation, and the opposite is true in the SACMET96 simulation. If the TODs were the same, it is likely the TOD, Light Rail, and Advanced Transit scenario simulated in MEPLAN would be superior to the Pricing & Light Rail scenario. Note also that travel and emissions results were relatively close between the two MEPLAN scenarios.

The magnitude of change from the Pricing & Light Rail scenario compared to the Base Case scenario is significantly greater in the MEPLAN scenarios compared to the SACMET96 scenarios. For example, the change in VMT for the Pricing & Light Rail scenario in SACMET96 is –0.6% compared to a change in VMT for the Pricing & Light Rail scenario in MEPLAN of -6.8%. However, because we did not control for differences between the travel models in MEPLAN and SACMET, we cannot make any conclusions about the significance of the land use and transportation interaction in this result.

VII. Summary and Conclusions

In this study, an advanced travel demand model and an integrated land use and transportation model were used to simulate land use, transit, and auto pricing policies in the Sacramento region. The application highlights several advantages of using multiple models to address the uncertainties in large-scale urban models by informing heuristic policy analysis.

In general, the results of both the MEPLAN and the SACMET96 model indicate that land use, transit, and/or auto pricing policies are effective at reducing auto travel and emissions in the Sacramento region over a 20-year time horizon, particularly when these results are compared to other policy scenarios evaluated with these models (Rodier and Johnston, 1997; Rodier, Johnston, & Abraham, 2000; Johnston and de la Barra, 2000). The results suggest that land use and transit policies may reduce VMT and emissions by approximately 5% to 7% compared to a future base case alternative. The addition of modest pricing policies to land use and transit measures may reduce VMT by about 9% to 10% and emissions by 7% to 17%. These results are generally consistent with those in the literature.

The operationalization of the policy scenarios in each model exemplified their theoretical and structural differences. The MEPLAN model represents land markets with endogenous prices and market clearing in each period. These features of the model allow for the use of market mechanisms to implement a land use policy that increases densities along light rail lines in the regions. SACMET96 is a travel model that uses fixed land uses. As a result, land uses were manually adjusted based on the land use densities of existing areas in the region that were considered to be prototype TODs. This approach assumes a command and control approach to implementing the TOD scenario. The SACMET96 model’s strength lies in its detailed representation of zones, transportation networks, and zonal walk and bike accessibility variables. Smaller zones allow more accurate representation of TODs. Pedestrian environmental factors in the model allow for the representation of improved walk and bike facilities in the TODs. Detailed transportation networks allow for accurate representation of the quality of available travel modes. MEPLAN does not represent geographic detail at this scale. MEPLAN uses large zones and a sketch network.

The comparison of the results from the two models illustrates the implications of the respective models' strengths and weaknesses and provides some insights into heuristic policy strategies. First, when we compared the effectiveness of the command and control approach to implementing the TODs in the SACMET96 model to the market mechanism in the MEPLAN scenario, the densities were much lower in the MEPLAN TODs than in the SACMET96 TODs. It is very unlikely that the greater detail of the TODs represented in the SACMET96 model would explain this difference. This suggests that the TOD densities in SACMET96 could not be achieved through tax and subsidy policies alone and that strict growth controls elsewhere in the region would also be needed. This is a tentative conclusion, however, because we have not controlled for the differences between the models. We believe it is not the absolute conclusion that is important here, but the insight gained from the comparison that suggests a new and more effective policy combination that could be tested in the MEPLAN model (i.e., tax and subsidy policies with growth controls).

Second, in the Pricing, TOD, Light Rail & Advanced Transit scenario, we found that the parking pricing policy in many of the TOD zones offset the benefits of subsidies and tended to dampen the migration of households and employment to those zones. In addition, we found in the Pricing & Light Rail scenario, the parking pricing policy in the

CBD resulted in a loss of employment as businesses relocate to nearby zones to avoid parking charges. This is because MEPLAN represents land markets and their relationship to transportation costs. These findings suggest that parking pricing should not be imposed in areas served by light rail lines and in areas in which increased densities are promoted with land subsidy policies. Thus, the theoretically comprehensive model, MEPLAN, is able to identify potential synergistic effects or the lack of synergistic effects among policies and suggests new and more effective combinations of policy scenarios.

The results of this study indicate that theoretically comprehensive urban models such as MEPLAN provide important insights into the development of heuristic policy strategies to address air quality problems, insights that in many cases may not be obtained from UTP-type travel demand models. The comprehensiveness of integrated land use and transportation models often comes at the expense of the detailed representation of geographic detail that is needed for vehicle emissions analysis. However, the failure to represent the relationship between land use and transportation in simulation studies may also compromise its accuracy, particularly over time.

It is possible to integrate a travel demand model with finer geographic detail into the MEPLAN framework; however, its development may be time-consuming due the difficulties of calibrating such a model. Recent advances in calibration methods may address this problem and reduce the time and monetary cost of developing such a model (Abraham, 2000). In addition, land use models can be developed for use with typical regional travel demand models. However, in many regions in the U.S., travel demand models would need to be significantly improved to better represent travel time and cost throughout the model hierarchy.

REFERENCES

Alonso, William (1968). Predicting the best with imperfect data. *AIP Journal.*

ABAG (1991). Assessing the Future: A Sensitivity Analysis of Highway and Road Improvements on Growth in the San Francisco Bay Area. Working Paper 91-4, Oakland, CA.

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

Breheny, M. J. (1992). The Contradictions of the Compact City: A Review. *Sustainable Development and Urban Form*, ed. by M.J. Breheny. Pion, London.

Breheny, M., T. Gent, and D. Lock (1993). Alternative Development Patterns: New Settlement. U.K. Dept. of the Environment. HMSO, London.

Cambridge Systematics Inc. (1994). *The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior*. U.S. Department of Transportation, Washington, D.C.

Cambridge Systematics Inc. et al. (1996). *Analysis of Alternatives. Making the Land Use Transportation Air Quality Connections*. Portland, Oregon, (May).

Cambridge Systematics Inc and DHS (1994). *The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior*. Travel Model Improvement Program. Department of Transportation, Environmental Protection Agency, and Department of Energy.

Cervero, R. (1988). Land-Use Mixing and Suburban Mobility. *Transportation Quarterly*, *42*, 429-446.

Cervero, R. (1994a). Transit-Based Housing in California: Evidence on Ridership Impacts. *Transport Policy*, *1*, 174-183.

Cervero, R. (1994b). Transit villages: from idea to implementation. *Access*, *5*, 8-13.

Crane, R. (1996). Cars and drivers in the new suburbs: linking access to travel in neotraditional planning. *Journal of the American Planning Association, 62: 1,* 51-65.

Delucchi, M. A. (1997). *The Annualized Social Cost of Motor Vehicle Use in the U.S., 1990-1991: Summary*. Institute of Transportation Studies, University of California, Davis, (June).

DKS Associates (1994). *Model Development and User Reference Report*. Sacramento Area Council of Governments, Sacramento, CA (October).

Dunphey, R. T., and K. Fisher (1996). Transportation, Congestion, and Density: New Insights. *Transportation Research Record, 1552*, 89-96.

Echenique, M. H. (1994). Urban and regional studies at the Martin Centre: its origin, its present, its future. *Environment and Planning B*, *21*, 517-533.

Ecotech Research and Consulting (1993). Reducing Transport Emissions Through Planning. U.K. Dept. of the Environment. HMSO, London.

Ewing, R. (1997). Is Los Angeles-Style Sprawl Desirable? *Journal of the American Planning Association, 63:1*, 107-126.

Ewing, R. (1995). Beyond Density, Mode Choice, and Single-Purpose Trips. *Transportation Quarterly, 49: 4*, 5-24.

Ewing, R. (1996). *Best Development Practices—Doing the Right Thing and Making Money at the Same Time*. Chicago, IL: American Planning Association (in cooperation with the Urban Land Institute).

Ewing, R. (1997). Is Los Angles-style sprawl desirable*?* *Journal of the American Planning Association, 63: 1* (Winter), 107-126.

Ewing, R., R. Haliyur, and G. W. Page (1994). Getting around a traditional city, a suburban PUD, and everything in-between. *Transportation Research Record, 1466*, 53-62.

Frank, L. D. (1994). The Impacts of Mixed-Use and Density on the Utilization of Three Modes of Travel: The Single-Occupant Vehicle, Transit, and Walking. Preprint 940425. Transportation Research Board, Annual Meeting. Washington, D.C. (January).

Gordon, P. and H. W. Richardson (1997). Are Compact Cities a Desirable Planning Goal? *Journal of the American Planning Association, 63: 1*, 95-106.

Holtzclaw, J. (1994). Using Residential Patterns and Transit to Decrease Auto Dependence and Costs. Natural Resources Defense Council testimony before the California Energy Commission, (June).

Hunt J. D., and M. H., Echenique (1993). Experiences in the application of the MEPLAN framework for land use and transportation interaction modeling. Proceedings of the 4th National Conference on the Application of Transportation Planning Methods, Daytona Beach, Florida, USA, (May), 723-754.

Johnston, R. A. and R. Ceerla (1995). Land Use and Transportation Alternatives. *Transportation and Energy: Strategies for a Sustainable Transportation System*, ed. By D. Sperling and S. Shaheen. ACEEE, Washington, D.C.

Johnston, R. A. and T. de la Barra (2000). Comprehensive regional modeling for long-range planning: linking integrated urban models and geographic information systems. *Transportation Research A, 34*, 125-136.

Kenworthy, J., and P. Newman (1989). *Cities and Automobile Dependence: An International Sourcebook.* Gower Technical, Adlershot, UK.

Keyes, D.L. (1976). Energy and Land Use: An Instrument of US Conservation Policy? *Energy Policy, 4:3*, 225-236.

Kitamura, R., P. L. Mokhtarian, and L. Laidet (1995). A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. *Transportation 24*: 125-158.

May, J. H., and G. J. Scheuernstuhl (1991). Land use, transportation and air quality sensitivity analysis. Preprint for the Transportation Research Board 70th annual meeting, January, Washington, D.C.

Morgan M., and M. Henrion. (1990). *Uncertainty.* Cambridge University Press, Cambridge, MA.

Nowlan, D. M., and G. Stewart (1991). Downtown Population Growth and Commuting Trips: Recent Experience in Toronto. *Journal of the American Planning Association, 57*, 165-182.

OECD (1995). *Urban Travel and Sustainable Development*. European Conference of Ministers of Transport.

Parsons Brinckerhoff Quade and Douglas (1996). *TCRP Report 16. Transit and Urban Form*. U.S. Department of Transportation.

Replogle, M. (1990). Computer Transportation Models for Land Use Regulations and Master Planning in Montgomery County, Maryland. *Transportation Research Record 1262*, 91-100.

Rodier, C. J., and R. A. Johnston. (1997). Travel, Emissions, and Welfare Effects of Travel Demand Management Measures. *Transportation Research Record 1598*, 18-24.

Rodier, C. J., R. A. Johnston, and J. E. Abraham (2000). Air quality analysis of transportation plans: is it important to model the land use effects? Department of Environmental Science and Policy, University of California, Davis.

Schimek, P. (1996). Household Motor Vehicle Ownership and Use: How Much Does Residential Density Matter? Preprint 969472. Transportation Research Board, Annual Meeting, Washington, D.C., January.

Sewell, W. R. D., and H. D. Foster (1980). *Analysis of the United States Experience in Modifying Land Use to Conserve Energy*. Working Paper No. 2, Lands Directorate, Canada.

Simmonds, D. (1995). Available Methods for Land-Use/Transportation Modelling. David Simmonds Consultancy.

Small, K. A., and H. S. Rosen. (1981). Applied Welfare Economics with Discrete Choice. *Econometrica, 49*, 105-130.

Steadman, P., and M. Barrett (1990). *The Potential Role of Town and Country Planning in Reducing Carbon Dioxide Emissions*. The Open University, Milton Keynes, UK.

Watterson, W. T. (1991). Linked simulation of land use and transportation systems: developments and experience in the Puget Sound Region. Paper for the Conference on Transportation and Global Climate Change: Long-Run Options, Transportation Research Board, Asilomar, CA, August.

Webster, F. V., P. H. Bly, and N. J. Paulley, eds. (1988). *Urban Land-Use and Transport Interaction: Policies and Models*. Avebury (Brookfield, MA).

Wegener M. (1994). Operational Urban Models, *Journal of the American Planning Association, 60: 1* (Winter), 17-29.