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The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land Use Change

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The University of California
Transportation Center

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Preface and Acknowledgements

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Each of the listed authors made a significant contribution to the research effort. Among the students, Allison Dobbins carried out the case studies and wrote the original draft of Chapter 5 Mohnish Puvathingal collected much of the data used in the study. He also participated in the preparation of Chapter 4, performing the regressions and writing much of the original draft. Yuanlin Huang provided excellent assistance in the preparation of Chapter 6, collecting and analyzing data as well as writing.

David Gillen, Research Economist at ITS, was primarily responsible for Chapter 4. He also reviewed and made many helpful comments on the entire draft report, and helped prepare the Executive Summary.

Mark Hansen was the Principal Investigator of this project. He drafted Chapters 1, 2, 3, 6 (in conjunction with Yuanlin Huang), and 7. He was also responsible for editing the drafts of the various chapters into (he hopes) a polished report.

The research team benefitted from the assistance of many individuals. Over a dozen planners and developers granted interviews for the case studies; they are listed on Page 5-45. Y.B. Yim and Hisham Noemi, of the California PATH program, made significant contributions in getting the project started.

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Executive Summary

Background and Motivation

Since the mid-1970s, traffic congestion on California's urban highways has increased markedly. The roughly 3 per cent annual growth in the ratio of vehicle-miles to lane-miles that occurred during the 1960s accelerated to 4 per cent from 1974 to 1985 and 5 per cent after 1985. Moreover, there was comparatively little upgrading of existing lane-miles over this period. As traffic density increased, so did congestion. By 1988, some estimates put the economic cost of congestion to California at $16 billion in time lost and $1 billion in fuel Despite a California Division of Highways Plan, developed in 1958, calling for 12 thousand miles of limited access roadways, by 1990 less than 6 thousand had been completed.

The curtailment in urban road construction can be attributed to economic, political, and environmental forces. The 1973 OPEC oil embargo, inflation, declining fuel tax revenues, and rising construction costs undermined the highway financing mechanism. Environmental and political opposition, initially localized as citizens fought projects in their neighborhoods, was by the mid-1960s accompanied by a national interest in air quality. In addition to legislation requiring improved emission controls on vehicles and measures to discourage automobile use, there was passage of broader environmental legislation mandating that the environmental consequences of government projects be explicitly identified, assessed, and when possible mitigated. This legislation significantly increased the resources and time required to deliver road projects.

Since road congestion results in increased fuel consumption and vehicle emissions per vehicle-mile. it is possible that the curtailment in highway investment has impaired progress toward improved air quality and energy efficiency. However, since the early 1970s, environmental advocates have opposed roadbuilding. They argue that roads generate traffic by discouraging transit use, promoting urban sprawl, encouraging longer trips, and through other mechanisms. Since the strategy of building roads to reduce congestion is doomed to failure, they advocate the shift of resources out of roadbuilding and into environmentally friendly alternatives. Recent air quality and surface transportation legislation seems to embody this view.

Despite the evolution of the environmental position into policy consensus, the reality may be contrary. Even with the significant reduction in roadbuilding, and despite massive investments in transit, vehicle travel has continued to grow both absolutely and in its share of the urban market. This suggests that traffic levels may in fact by rather insensitive to road supply. If this were the case, then highway capacity enhancement could result in both improved mobility and reduced vehicular emissions and fuel consumption.

Thus the potential benefit of capacity enhancement will depend upon its impacts on the quantity of vehicle travel. If, as roadbuilding opponents claim, traffic inducement is high, capacity enhancement will yield little improvement in traffic flow, reductions in emissions per vehicle-mile will be offset by increases in vehicle-miles traveled (VMT), and mobility gains from increased speeds may be counteracted by increased travel distances. If, on the other hand, traffic inducement is low, the impact of capacity enhancement will be more propitious in all these respects. The purpose of this research is to assess the traffic inducing impacts of highway capacity increases in order to better understand the potential benefit of capacity enhancement as a strategy for reducing traffic congestion and improving air quality. The scope of the research is limited to traffic inducement -- we do not attempt an overall appraisal of capacity enhancement as a transportation improvement strategy. The research focusses on "pure" capacity expansions as opposed to the construction of new facilities or significant upgrades (e.g. from a regular road to a controlled access facility) of existing ones.

The core of the project consists of several complementary empirical studies. The effect of increases in road capacity on the amount of vehicular travel is analyzed both at the level of individual highway segments and at the regional level. The effect of capacity increases on land development are examined in two studies: a series of case studies based on interviews with planners and developers, and an econometric model of building permit activity that employs statistical techniques to examine impacts and relationships

Traffic Generation from Highway Capacity Expansion

To measure the effect of capacity expansion on traffic level, we use the concept of elasticity In general, the elasticity of Y with respect to X is the per cent change in Y resulting from a 1 per cent increase in X The elasticity may also be measured as the ratio of the change in the logarithm of Y to the change in the logarithm of X. For small changes in Y and X, these measures yield virtually identical results, but for large changes they diverge somewhat. The elasticities presented in this report are, for the most part, based on the logarithm calculation method.

Two chapters of the report are specifically concerned with estimating the elasticity of traffic with respect to capacity. In Chapter 3, both traffic and capacity are measured for individual road segments. In Chapter 6, the unit of observation is an area -- either a county of an entire urban region In this case traffic is measured in terms of VMT in the area, and road supply in terms of lane-miles.

The analysis in Chapter 3 is based on annual traffic counts for a set -- or "panel" -- of 18 road segments belonging to the California State Highway System whose capacity was expanded by adding traffic lanes at some time over the past 30 years. We estimate models relating the traffic on a segment to its capacity Two types of models are developed. In the first, the traffic level on a segment is related to the capacity of the segment, the proportion of the capacity that is new and how long the new capacity has been in place, and the overall traffic level on the state highway system. In the second model, traffic growth on the segment is the dependent variable, and is related to the amount of available capacity (measured as the difference between 1 and the volume-capacity ratio), and the growth of state highway system traffic.

Estimation results for both the traffic level and the traffic growth models indicate that traffic level (or traffic growth) is positively related to capacity (or available capacity). The results for both models also reveal that, when capacity is added to a segment, the traffic level responds over an extended period of time -- at least one decade and possibly two It is therefore necessary to define a time-dependent traffic-capacity elasticity, which we designate $\varepsilon_{qc}(t)$. For example, ε_{qc}(8 years) is the per cent difference between the traffic 8 years after a 1 per cent capacity expansion[1] and what the traffic would be in that same year had the expansion not occurred.

We use the calibrated models -- the growth model and several variants of the level model with differing assumed values of a parameter -- to estimate values for $\varepsilon_{qc}(t)$ for t values ranging

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[1] Obviously, a 1 per cent capacity expansion is much smaller than what is obtained when lanes are added to a roadway It is used for definitional purposes only

from 4 to 19 years. Different models yield different estimates. Taking into consideration the central tendency of these estimates, as well as reasons for discounting results of certain models, we estimate $\varepsilon_{qc}(t)$ to be in the ranges 0.15-0.3, 0.3-0.4, and 0.4-0.6 for t values of 4, 10, and 16 years respectively. These estimates may not be accurate for any particular expansion project, but reflect a statistical composite of the 17 projects considered in our analysis. Qualitatively, they imply that, while capacity expansion clearly results in additional traffic, it also reduces the volume-capacity ratio (since the elasticity is less than 1), and thereby improves the level of service, for an extended length of time.

Our analysis of the relation between road supply and traffic at the area level is also based on statistical analysis of panel data In this case, our panel consists of California's urban counties We also consider aggregates of these counties that form Metropolitan Statistical Areas (MSAs) or, in the case of San Francisco and Los Angeles, Consolidated Metropolitan Statistical Areas (CMSAs). Using data for the period 1973-1990, and controlling for other variables such as population and income, we estimate log-linear models[2] relating VMT to lane-miles of state highway at both the county and CMSA/MSA level. We employ two different VMT measures, one for state highways only and the other for all public roads. Unfortunately, the latter VMT figure is available only for five recent years. Thus, our most conclusive findings concern the relationship between state highway VMT and state highway lane-miles

Different versions of the basic model are estimated. The most important difference among these versions is whether a set of regional correction factors is employed. By including the regional correction factors, we reduce the possibility that effects of regional variables omitted from the model are incorrectly attributed to road supply or some other included variable However, these factors also absorb effects of interregional differences in the values of independent variables that are consistent over time. In other words, when regional correction factors are used, the estimated elasticity of VMT with respect to lane-miles will reflect the relation between intraregional growth in VMT and intraregional growth in lane-miles over the

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[2] A log-linear model has the form $\log(Y)=A_0+A_1\cdot\log(X_1)+\ldots+A_n\cdot\log(X_n)$ One convenient property of the model is that elasticities can be read directly from the coefficients $\epsilon_{YX_i}=A_i$

1973-1990 period. Conversely, if the regional corrections are not employed, interregional VMT and lane-mile variation will dominate the estimation results. We therefore refer to the models with regional correction factors as "intraregional," and those without them as "interregional."

Our estimation results for both intraregional and interregional models reveal a statistically significant effect of state highway lane-miles on state highway VMT. At the county level, the intraregional model lane-mile elasticity is in the 0.46-0.50 range while for the interregional model it is around 0.32-0.33 At the MSA/CMSA level, the intraregional lane-mile elasticity is 0.54-0.61 and the interregional one is 0.24. In addition to the consistently positive, statistically significant, lane-mile elasticity estimates, our results indicate that intraregional elasticities are somewhat higher than interregional ones. Our explanation for this is based on the fact that the intraregional model is based on lane-mile additions since 1973, while the interregional one is based on the entire stock of state highway lane-miles. We conjecture that most urban lane-mile additions after 1973 were for the specific purpose of congestion relief, while earlier construction was more oriented toward creating the basic freeway system. Therefore the additional lane-miles added after 1973 had a more pronounced effect on level of service, and thus on traffic.

The relationship between state highway lane-miles and total VMT is more difficult to investigate, because data for total VMT is available for fewer years, and the period for which it is available saw little change in lane-miles Generally, the estimated lane-mile elasticities of total VMT obtained from the intraregional and interregional models are close to the state highway VMT estimates.[3] However, the intraregional estimate is statistically insignificant -- we cannot reject, on the basis of this model, the null hypothesis that total regional VMT is unrelated to state highway lane-miles in the region. Since the interregional estimate is statistically significant, and since both estimates are similar in magnitude to those for state highway VMT, we believe that the intraregional estimate is insignificant because there simply has not been enough change in lane-miles over the period of the analysis to allow the effect of this variable to be observed.

Comparison of the segment-level and area-level analysis results provides further insight concerning the relationship between highway capacity enhancement and traffic generation It appears that elasticity of traffic level with respect to road capacity is somewhat higher at the

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[3] The total VMT model was estimated only at the MSA/CMSA level

regional level than at the segment level. The regional results reflect two effects not observed at the segment level. The first is route diversion, which would result in traffic losses on other segments that are potential substitutes for the expanded segment. The second, is additional travel on segments that are complementary to the expanded one, i.e. segments that users of the expanded segment also use on the same trip. Thus, since traffic-capacity elasticities are higher at the regional level, it appears that the complementary effect is stronger than the substitution effect -- an expanded segment generates more traffic on other parts of the system than it removes.

Land Use Impacts of Highway Capacity Expansion

The other main component of the study concerns whether and how highway capacity expansion influences land use. Land use impacts are given special consideration because, if they occur, they are likely to be an important part of the mechanism leading to traffic generation Also, since conventional transportation planning models treat land use as exogenous, they are likely to yield incorrect results if road capacity enhancements stimulate land use changes.

Two different approaches are used to study the relationship between land development and capacity enhancement. First, we perform an econometric analysis of building permit activity in communities likely to be affected by freeway capacity expansions that have occurred over the last two decades. We employ time series data on permit approvals of four different types: single family housing, multi-family housing. office development, and industrial development. We then estimate models relating the affected communities' share of permit activity, relative to the urban region in which they are located, to a set of independent variables, including whether the expansion had occurred and, if so, the time elapsed since the expansion We estimated the model on a panel consisting of eight corridors where freeway expansion occurred. Thus, as in the other traffic impact analyses, our results characterize the composite impact of a set of expansions on a set of corridors, rather than what occurred in any specific corridor.

We find that single family residential development increased sharply after completion of the capacity additions but the rate of development decreased after the initial spurt. The impact on multi-family housing land use is similar to that on single family housing but lower overall in magnitude. The rate of commercial land use development rises after completion of the capacity enhancement and continues to accelerate, albeit at a declining rate, for a period of several years. In the case of industrial development, capacity enhancement does not appear to have an immediate effect, but does seem to initiate an upward trend in corridor activity. These results imply that the land use changes brought about by the increase in highway supply will lead to greater traffic potential along the corridor. This does not, however, in and of itself imply an increase in either corridor or regional traffic, because increases in tripmaking resulting from the intensification of land use may be partly or wholly offset by reductions in average trip lengths. We also do not know whether the development induced in the corridor displaced development that would have taken place elsewhere in the region, had the capacity expansion not occurred.

The results of the statistical analysis of land use changes are in apparent conflict to the conclusions of the case study analysis. Planners and developers indicated that capacity enhancements played a negligible role in their decisions to allow or undertake developments in nearby communities, even though they recognized highway access as an important factor in making decisions. We believe that such apparent contradictory results arise from a different focus of planners and developers, who consider land variables, such as price and accessibility, rather than highway variables, in making decisions with regard to building and developing. Thus, if a change in highway capacity changes land prices, development may be affected without developers recognizing the role of the road project Similarly, developers acknowledged that commute times and local road conditions were important in their decision-making. These tend to be highly correlated with highway capacity expansion and yet the developers perceive the correlates, while overlooking the capacity expansion itself.

Implications

Our results do not provide a conclusion to the question, "should we expand highway capacity to alleviate congestion and reduce emissions?" Our results do, however, provide information that may temper the positions of both road proponents and opponents To advocates of roadbuilding, we point out that -- at least for state highways -- capacity expansion does increase traffic both on the expanded facilities and in the larger urban area. The magnitude of the impact grows with time. There is also evidence that conventional transportation planning models tend to underestimate traffic generation of capacity enhancements, since they fail to consider land use impacts. To opponents of roadbuilding we stress that capacity expansion reduces volume-capacity ratios, increasing the level of service for an extended, if not indefinite, period of time Traffic does not expand to fill this capacity for over 20 years In short, roadbuilding can hardly be viewed as a futile effort to satisfy an insatiable demand, except perhaps in the very long run

We conclude that the debate over urban roadbuilding as a means of relieving traffic congestion is to a large degree a question of the relative importance of short run and long run considerations. Capacity expansion promises immediate congestion relief, and probably an accompanying reduction in emissions and fuel consumption As traffic levels respond, the congestion benefit is reduced, and overall emissions and fuel consumption may increase. Expected improvements in automotive technology that will enhance fuel efficiency and reduce emissions further complicate the issue, since these should reduce the environmental and energy costs of congestion, and vehicle travel generally, in the future. In light of these considerations, much further study is required before a comprehensive assessment of roadbuilding as an urban transportation improvement strategy can be made.

Chapter 1:

Introduction

1.1 Background

Since the mid-1970s, traffic congestion on California's urban highways has increased markedly. The ratio of vehicle-miles traveled (VMT) to lane-miles on the system has increased consistently since well before that time -- indeed, since records have been kept. During the 1960s, however, the increase was moderate (roughly 3 per cent annually) and largely absorbed by the qualitative improvements to the system (upgrades from regular to controlled access facilities). From 1974 to 1990, the traffic-capacity ratio increased at an accelerating pace, averaging 4 per cent over the entire period and 5 per cent after 1985. Further, this period witnessed comparatively little upgrading of existing lane-miles

As ratios of vehicle-miles to lane-miles have increased, so has the exposure of California drivers to sluggish and stop-and-go traffic, both in periods of the day when volumes regularly approach capacities (recurring congestion), and when accidents or other events result in temporary reductions in capacity (non-recurring congestion). The Road Information Program (TRIP), a group that lobbies for increased roadway investment on behalf of the construction industry, estimates that in 1988 congestion cost Californians some $16 billion in time and $1 billion in fuel (TRIP, 1990).

The data clearly show that increased congestion derives, not from a surge in vehicle travel, but from a curtailment in highway building in the face of steady traffic growth. Between 1963 and 1974, California state highway lane-mile growth averaged 2.2 per cent annually, while traffic grew at 5.2 per cent per year. After 1974, traffic growth decreased slightly -- to 4.4 per cent, but annual lane-mile growth virtually stopped, averaging 0.3 per cent through 1990. These figures reflect the collapse of one of the most ambitious public works programs of modern times The 1958 California Division of Highways Freeway Plan (California Division of Highways, 1958), prepared to guide state highway programming for the next several decades, called for a system ultimately consisting of some 12 thousand miles of limited access roadways. As of 1990, less than 6 thousand miles had been completed.

The collapse of the Freeway Plan can be attributed to several factors. First, the 1973 OPEC oil embargo undermined the highway finance mechanism. As vehicles became more fuel efficient, receipts from the per gallon gasoline tax shrank. Meanwhile, inflation accelerated. These events resulted in a sharp curtailment in the level of highway construction that could be supported Real dollar expenditures for highway construction in California dropped 75 per cent between 1970 and 1976 (Jones, 1989).

Other factors also played an important role in curtailing the highway program. From the time work on the system began, highway construction projects encountered fierce local opposition in some areas. In California, the first such confrontation occurred in San Francisco, where, in 1956, neighborhood groups protested plans to build a second generation of freeways through residential areas (Jones, 1989). Such "freeway revolts" eventually spread to other cities, including Sacramento, Santa Barbara, Monterey, and Los Angeles (Jones, 1989)

Beginning in the mid-1960s, these localized concerns were accompanied by a national interest in air quality, resulting in state and national legislation that mandated improved emissions controls on vehicles, established ambient air quality standards, and called for the use of transportation control measures to discourage motor vehicle use in areas not meeting the standards. Additionally, the late 1960s witnessed the passage of broader environmental legislation, both in California and nationally, that required that the environmental consequences of government projects -- including highway construction -- be explicitly identified and assessed in a decision process open to pubic participation.

Although there are instances of neighborhood and environmental opposition stopping specific road projects, their more important impact was to increase the resources and time required to deliver highway projects. This effect is difficult to measure precisely. but indexes reported by Jones (1989) for California are suggestive. According to these figures, real construction expenditure (adjusted for the escalating cost of construction) in the 1977-80 period was 31 per cent of its level in the 1970-73 period, but miles of freeway completed in the later period was only 13 per cent of that in the earlier one. In other words, construction cost increases and declining gas tax revenues led to a 2/3 reduction in roadbuilding between these two periods, while other factors -- undoubtedly including increased requirements for environmental review and mitigation -- led to an additional 50 per cent cut [1]

1.2 Highway Investment and Clean Air -- The Roots of Polarization

In retrospect, a case can be made that both the environmental and economic forces that undermined the California highway program had, by virtue of the resulting increases in traffic congestion, perverse effects. Congested traffic conditions lead to frequent accelerations and decelerations, as well as low operating speeds where engine operating efficiency is suboptimal. This results in increased emissions of hydrocarbons (HC) and carbon monoxide (CO), and greater fuel use per vehicle-mile. While other changes brought on by fuel cost increases and environmentalism, such as emission controls, lighter vehicles, and improved engine efficiencies, may have more than counteracted the negative impacts of increased congestion, one can certainly question whether the near cessation in highway building aided the cause

Yet, since the 1970s, roadbuilding has been viewed by environmental advocates and many others as antithetical to their goals. The basic premise for this position is that roads generate traffic. Thus, in the 1970s, the ever increasing growth in motor vehicle travel and resulting air pollution was viewed to be, at least in part, the result of past roadbuilding excesses. According to one version of this theory:

> The problem is that Californians are really trapped in a closed circle of tax and expenditure and construction that will continue to build roads endlessly ... The circular trap is roughly as follows. Cars use gasoline and taxes are collected. The taxes <u>must</u> be spent for new roads, there is no choice. New roads are built. As these roads are built, they encourage more and more people to drive more and more miles. More miles mean more gas, more tax, more revenue, more roads and on and on (Stanford Environmental Law Society, 1971).

In another version of the "roads generate traffic" theory, Mogridge (1985) emphasizes the interaction between highway and transit level of service. According to his theory, commute travel times by auto and transit will equalize. If road capacity is added to relieve congestion, the reduction in travel times will attract transit users until travel times are again equal. However, because of economies of scale (in particular, service frequency and route density effects) in

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[1] On top of this, political opposition to roadbuilding undoubtedly played an important role in discouraging efforts to address the shortfall in gas tax revenue caused by OPEC oil price increases

transit, the new equilibrium -- by virtue of having lower transit ridership -- will have higher transit travel times, and hence higher auto times as well. Thus, adding road capacity is predicted to generate so much traffic that a <u>reduced</u> level of service on the facility results.

Others, while admitting that adding road capacity may increase travel speeds, argue such benefits are offset by longer trip lengths. Altshuler (1979) notes that Los Angeles residents, despite having a more extensive and less congested freeway system than Bostonians, spend an average of 20 per cent more time commuting. From this, he concludes that "urban residents have historically purchased reductions in land use density with their highway expenditures far more significantly (and durably) than they have purchased travel time savings."

The traffic inducing effect of roadbuilding is often linked to its impacts, along with those of other infrastructure investments, on land use. According to the Council of Environmental Quality (1976).

> The economic and environmental impacts of development induced by new infrastructure are of growing concern to all levels of government, for the direct local benefits provided by the infrastructure may be seriously reduced or even outweighed by indirect changes resulting from changes in local land use.

Perhaps it is William Mulholland, former water superintendent of the of the city of Los Angeles, who states this position most succinctly. "If you don't get the water, you won't need it (Sierra Club, 1982)."

While differing in their details, all of the above arguments imply that adding road capacity to prevent or reduce highway congestion is likely to be a futile strategy. By the same token, they point to another solution, suggesting that motor vehicle travel could be substantially curtailed by shifting resources out of highway construction programs and into environmentally friendlier alternatives such as mass transit and transportation systems management. Combined with other changes -- land use intensification, balanced development patterns, pedestrian-oriented design -- this redirection of transportation resources is expected to result in urban areas with cleaner air, more open space, and long-term sustainability.

Now, some two decades after roadbuilding became a focus for environmentalist criticism, its de-emphasis as a solution to the urban transportation problems has seemingly become a policy consensus. This is suggested by recent legislation, such as the 1990 Clean Air Act Amendments

(CAAA), the 1991 California Clean Air Act, and the 1991 Intermodal Transportation Efficiency Act (ISTEA). The CAAA identifies 16 types of transportation control measures (TCMs) for consideration by areas that have not attained air quality standards (Altshuler and Howitt, 1992). Of these, just one --"traffic flow improvements" -- could be construed as involving road capacity enhancements. On the other hand, 11 of the suggested TCMs, ranging from improving bicycle facilities, to improved public transit, to direct restrictions on vehicle use, are solely aimed at reducing the number of vehicles on the road. The Transportation Performance Standards of the California Clean Air Act (California Air Resources Board, 1991), in calling for "substantial reductions" in vehicle travel and a 1.5 passenger per vehicle occupancy standard (but no adequate road capacity standard) also reflect this philosophy. Likewise, the funding provisions of ISTEA greatly increase the opportunities for states and localities to shift Federal funds from road programs into transit and other programs intended to reduce vehicular travel. The ISTEA mandate that transportation improvements further air quality goals has been interpreted as a requirement to de-emphasize road improvement projects, rather than initiate them in congested areas.

Political support does not imply empirical verification. Recent legislation notwithstanding, the last two decades have not been kind to many of the arguments articulated in the previous section. Despite a sharp reduction in roadbuilding, growth in vehicle travel has continued almost unabated (see Section 1.1). Despite substantial investments in urban transit, its share of the urban travel market has continued to shrink. Increasingly stringent measures to increase commuter vehicle occupancy have found only marginal success. These and other developments since the 1970s point to an interpretation in sharp contrast to Mulholland's adage. We didn't get the road capacity, but we still need it.

1.3 Objective and Approach of the Research

With congestion at high and ever increasing levels in many urban areas, congestion relief is a widely accepted means for both improving mobility and reducing vehicular emissions. As noted above, environmental and transportation policy has increasingly focussed on traffic reduction rather than capacity addition Although efforts to reduce vehicular traffic will undoubtedly continue to play an important role in urban transportation planning, the potential contribution of capacity enhancement must also be considered. Compared with demand reduction strategies, capacity enhancement is less coercive, less dependent on behavior modification, and potentially more conducive to mobility. But for all these advantages, the potential benefit of capacity enhancement measures depend on the extent to which they induce traffic. If, as roadbuilding opponents claim, traffic inducement is high, capacity enhancement will yield little improvement in traffic flow, reductions in emissions per vehicle-mile will be offset by the increased VMT, and mobility gains from increased speeds may be counteracted by increased travel distances If traffic inducement is low, the impacts of capacity enhancement will be more propitious in all these respects.

The purpose of the research reported in these pages is to assess the traffic inducing impacts of highway capacity increases, in order to better understand the potential benefit of capacity enhancement as a strategy for reducing traffic congestion and improving air quality The focus is limited to traffic inducement -- a comprehensive assessment of the capacity enhancement strategy is not attempted. On the other hand, in light of the concerns discussed above, this research represents a crucial first step toward such an assessment.

Highway capacity increases can take many forms, but in this report we consider only the clearest cut examples -- projects that involve constructing additional lane-miles of highway. This restriction was motivated by our intention to establish quantitative relations, and consequent need to quantify capacity in a simple, straightforward way. Although our focus is on lane-mile additions, many of the results likely apply to other types of capacity enhancements as well.

Lane-mile additions themselves take various forms. In this research, we are mainly concerned with projects involving the widening of existing facilities. This emphasis is in part pragmatic -- based on the paucity of recent experience with and limited future prospects for constructing entirely new facilities. Additionally, we wish as far as practicable to focus on "pure" capacity increases rather than improvements that also increase mobility under free flow conditions, the traffic inducing impacts of which are potentially quite different. However, since many road improvements, even those to existing facilities. offer some benefits even under free flow conditions, we cannot be too rigorous in applying this criterion.

While informed by theory, our inquiry is empirical, based on a posteriori analysis of the impacts of projects in the 1970s and 1980s. Using different units of analysis (individual road segments, urban regions, etc.), we assess how traffic and traffic-generating activities respond to lane-mile additions. The "raw empiricism" employed in this study distinguishes it from conventional techniques for evaluating transportation improvements, using transportation planning models We have adopted this approach because conventional planning models, for all the improvements they have undergone in recent years, have shortcomings that severely limit their credibility and utility in predicting the impacts of incremental changes in urban road systems. We place more reliance on methods that help us see impacts as they have actually occurred in the real, if statistically "noisy", world than those based on the simulated, if "noiseless", world of transportation planning models.

1.4 Research Components and Organization of the Report

This research consists of several self-contained, yet complementary, studies. First, a literature review examines previous work on road supply-demand relationships, ranging from before-after studies on individual segments to state-of-the-art transportation/land use models. The literature review is presented in Chapter 2 Second, the supply-demand relationship is studied at the level of individual highway segments. Chapter 3 presents the analysis of how segment traffic volume responds when the capacity of the segment is increased

In the next two chapters, the level of analysis shifts from individual links to corridors. These chapters focus on whether, and how, highway capacity increases affect land development in nearby areas. Although other impacts could also be studied at the corridor level, we concentrated on land use impacts for two reasons. First, land use impacts are typically not considered in conventional transportation planning models Second, data for the analysis were readily available. Chapter 4 analyzes these data, in order to determine whether rates of land development increase in response to road widening projects In Chapter 5, the same question is addressed in a different way, through a series of case studies involving review of planning documents and interviews with planners and developers. Interestingly, findings from these investigations are, at least superficially, in substantial conflict.

In Chapter 6. our analysis moves to the regional level. Here, we investigate the relationship between highway lane-miles and area traffic at the county and metropolitan levels. These relationships are analyzed both interregionally, through analysis of variation between different regions, and intraregionally, through analysis of the relationship between lane-mile and traffic growth in individual regions.

Finally, in Chapter 7, we attempt to draw together results from the previous chapters into a coherent picture of the traffic-inducing effects of road capacity enhancements. We also assess the policy implications of our results, and identify further research needs.

References -- Chapter 1

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Chapter 2:

Literature Review

2.1 Introduction

This chapter reviews the literature on the traffic inducing impacts of roadway improvements. As noted in the introduction, the practice of highway planning, both in the U S. and in other countries, has long been criticized for failing to adequately consider traffic inducing effects In its more extreme manifestations, this view becomes one in which any additions to roadway capacity are quickly and completely absorbed by additional traffic, creating a system with equal congestion and more vehicles. A moment's reflection refutes this notion -- it implies that all roads operate at capacity. On the other hand, it is equally implausible to deny that roadway capacity increases have any traffic inducing effects. This would imply either that congestion is unrelated to capacity, that (generalized) travel cost is unrelated to congestion, or that quantity of travel is unrelated to cost. All the links in this causal chain have strong empirical and theoretical bases

But while it is easy to rule out either of the above polar positions, it is considerably more difficult to establish where between them the truth lies. As is the case with many other transportation research questions, a fundamental problem is the inability to conduct controlled experiments. Each urban region is unique, and in a constant state of change in response to a host of influences, many of them stronger than adjustments to the road system. It is therefore difficult to attribute a given change in the region to a specific change in roadway supply The task is made even more challenging because highway supply changes are not made randomly, but in response to or anticipation of traffic conditions, thus clouding the direction of causality

Fortunately, these challenges have not discouraged researchers from investigating relationships between roadway supply and traffic. To the contrary, the impossibility of arriving at definitive results, combined with the wide range of applicable research methods, has led to a rich and varied literature. If, in the end, the relationships of interest remain elusive, much more is known about them now than was three decades ago

This chapter surveys current knowledge on the relationships between roadway supply and vehicular travel in urban regions. Following this introduction, Section 2 2 presents a taxonomy of possible links between these variables. Section 2.3 overviews the research methods that have been used to study these links, while the next several sections discuss findings from selected studies employing the various methods. Conclusions from the literature review are offered in Section 2 4.

2.2 Linkages between Roadway Supply and Vehicular Travel

Travel patterns in an urban region are the outcome of multiple, and for the most part private and decentralized, decisions involving travel, activity location, and land development. The impact of roadway supply on urban travel derives from its impacts on these various decisions. It is therefore appropriate to categorize the impacts of increased road supply in terms of the type of decision that is affected. The impact categories will be described in the context of the specific type of roadway supply change of interest to this study -- an increase in capacity to a pre-existing roadway Further, the different types of impacts will be related to the travel variables of primary interest to this study -- those relating to the overall amount of vehicular traffic in an urban region.

2.2.1 Travel Decisions

As used here, "travel decisions" refers to choices of what trips to make, when to make them, what modes to use, and what routes to take. We also place vehicle ownership decisions in this category, while admitting that they are of a somewhat different order than the others. Travel decisions are closely tied to location decisions, but for present purposes it is useful to distinguish them. With the possible exception of vehicle ownership, it is apparent that travel decisions are comparatively easy to change, and thus can respond to an increase in road capacity in a fairly short period. Despite this, travel behavior, like that in many other contexts, is subject to a high degree of inertia that may substantially prolong the adjustment period.

Of the different travel decisions, route choice is the most readily adjusted. If the capacity of a congested roadway is increased, the reduction in congestion should quickly attract some of the traffic from alternate routes. Initially, too much traffic may be attracted to the expanded facility, recreating the congestion and resulting in a subsequent adjustment in the opposite direction. Similar, though less pronounced, adjustments occur throughout a wider area, as routes parallel to the improved roadway become more attractive as a result of traffic diverting to the improved one.

Although the traffic reassignment impact of a roadway improvement is often pronounced, its impact of regional traffic levels is slight, and may lead to either an increase or decrease depending on the circumstances. As a general rule, reassignment toward higher level facilities such as highways and freeways tends to increase total travel, because such facilities have, on the average, greater access distances

Roadway capacity increases may also affect mode choice. The impact would be expected to occur when the relative travel time between alternative modes is affected -- if rail transit is employed or if buses make little use of the improved facility. The significance of the impact will be greatest where the transit mode share is greatest, for example central city work trips is large metropolitan areas. In contrast to traffic assignment, any impact of a roadway improvement on mode split will translate directly into an impact on total regional travel. As noted in Chapter 1, the impact would be particularly strong if a transit patronage loss triggered a reduction in transit service levels, resulting in a further mode shift.

Trip retiming can occur in response to a roadway capacity increase. When a road is congested during peak periods, peak broadening often results as trips are rescheduled to avoid the worst of the congestion. Conversely, a capacity increase would be expected to result in some narrowing of the peak. Obviously, retiming does not in and of itself have any impact on the quantity of travel either on the improved facility or in the region as a whole. It will, however, affect the proportion of travel made in congested conditions.

A fourth travel decision that may be affected by a roadway capacity increase involves choices that affect the number of trips, or trip generation These choices arise in a wide range of contexts. One broad category involves choices between activities which do and do not require travel -- for example between watching television and going to the movies A second major category concerns the level to which activities requiring travel are chained or consolidated in order to reduce the number of trips or amount of travel. Although the proportion of trips affected is probably quite small, there are undoubtedly cases where traffic conditions influence trip generation choices.

Roadway supply may also affect car ownership and car availability, and, through these, mode choice, activity location, and trip generation. For example, if a work trip is made by automobile, then the vehicle is not available to others in worker's household during the workday. A mode shift from transit to auto for the work trip may thus result in a net reduction in vehicular travel. On the other hand, since the utility of motor vehicles is greater when the road system offers a high level of service, vehicle ownership may increase, leading to an additional increase in vehicular travel.

Finally, it should be reiterated that in some situations -- shopping, for example -- travel decisions overlap with location decisions. However, most location decisions are somewhat more long term in nature than travel decisions, and are thus discussed below as a distinct category.

2.2.2 Activity Location Decisions

Activity location decisions made by firms, households, and individuals determine the origins and destinations of urban trips, and through these travel distances and the viability of different modal alternatives. In making location choices, decision makers balance transport considerations against other factors, such as land rent, availability and quality of services, compatibility with neighboring land uses, and neighborhood and environmental amenities. As urban mobility increases, non-transport considerations become increasingly influential, resulting in longer trips and a more decentralized travel pattern.

The most important location decisions are those involving home and workplace. The role of improved transport in encouraging employees to live further from their workplaces is well recognized. While most everyone would prefer a shorter work trip, the ability to make longer trips vastly increases the number of residential alternatives available. If roadway capacity enhancements increase feasible commuting distances, they are likely to increase actual commute distances as well.

The same principle applies to other location decisions. Just as workers are willing to commute longer distances in order to attain a less expensive or more desirable residence location, so are employers willing to locate at a greater distance from sources of labor supply in order to benefit from agglomeration economies or from lower land rents. Likewise, shoppers are willing to travel considerable distances to reach stores with low prices or a large selection of merchandise, while retailers, in turn, are willing to sacrifice proximity to customers in order to increase scale and reduce costs. In all of these cases, roadway capacity expansion can change the optimal point of trade-off between transport cost and other considerations.

There are, however, exceptions to this general pattern. When congestion is limited to a few specific links -- in the case of estuary crossings for example -- relatively short trips in certain corridors may be suppressed in favor of longer ones in less congested corridors. In these circumstances, a capacity increase, by improving accessibility from less distant points, could lead to a reduction in overall regional travel.

2.2.3 Development Decisions

Location decisions are conditioned by the availability of suitable housing, commercial, office, and industrial space. The supply of such space is the outcome of a complicated process in which both the private and pubic sectors play important roles, and in which both sectors can be influenced by roadway supply. Private developers want their properties to be attractive to prospective tenants and buyers. Recognizing the importance their customers place on accessibility, developers can be expected to respond when a roadway improvement increases the accessibility of a parcel Local and regional governments, on the other hand, are concerned with the impact of proposed developments on traffic, particularly when affected roadways are already congested. Existing or planned expansions of such roadways may therefore increase the prospects of a proposed project being approved

Just as increased traffic volume on an improved corridor may be either "new" or merely reassigned, development attracted to an improved corridor may represent either a net addition or a redistribution from other parts of the region. Even if the impact is redistributive, however, the development may have significant net impacts on regional travel, particularly if it represents a shift to the suburbs from the central city. Many suburban office developments, for example, appear to represent an exodus from downtown areas In light of the greater competitiveness of transit for central city as compared with suburban commuting, such a shift in activity location increases the share of person-trips made by low-occupancy vehicle, and possibly (depending on the impact on trip length) VMT as well.

The relationship between development decisions and roadway supply changes extends beyond the impacts of individual projects to the overall policy toward roadway expansion. Developers must anticipate the future, and their expectations about the future rest on past experience. Thus, a developer may build in an already congested corridor if this experience leads him to believe that the congestion will be alleviated in the future through road improvements. By influencing this climate of expectations, capacity expansion projects may affect development decisions throughout an area much larger than they directly influence.

2.3 Prior Studies of the Impact of Roadway Capacity Increases

While it is comparatively easy to identify possible links between roadway capacity enhancement and roadway traffic generation. it is difficult to isolate and quantify these effects. Many factors other than road investment influence the different decisions described above. Further, in a modern American city, any specific road improvement is unlikely to have more than a marginal influence. These two factors contribute to a low "signal-to-noise ratio" which must be overcome in order to obtain reliable measurements of the impacts of interest.

At the broadest level, previous research efforts fall into three categories those based on direct empirical analysis, those based on simulation using regional models, and those based on expert judgement.

In empirical studies, impacts of changes in road supply on traffic, land use, and other outcome variables are examined through direct observation of the real world. Empirical studies depend on naturally occurring variation in road supply, either over space or over time. Given this variation, investigators attempt to infer relationships between road supply and other variables. The inferences may be based on observed covariation between road supply and these variables, or on testimony of decisionmaking agents -- travelers and developers for example -- whose behavior may be affected. Studies based on covariation may employ simple before/after (or with-without) comparisons, or more elaborate and formal statistical methods The unit of observation in empirical studies ranges from specific road segments to entire regions.

The second broad category of studies consists of those based on regional models. These studies do not attempt to directly observe the impacts of changes in the roadway system, but rather to simulate these impacts. The primary advantage of this approach is that in simulations, unlike the real world, one specific variable can be changed while holding all others constant. Thus, the impact of a change in road supply on the outcome variables can be directly and unambiguously observed. The primary disadvantage of the model-based approach is the tremendous difficulty of developing and credibly validating a model of a regional transportation/land use system Consequently, regional models offer clarity, but not necessarily truth.

Within the category of model-based studies, there are two principal subgroups. The first uses models that roughly follow the traditional four-step urban transport modelling process, in which travel demand is predicted based on exogenous land use variables. In the second set of studies, models that predict land use as well as travel demand, and capture the mutual interaction between these variables, are employed.

The third category of studies, those based on expert judgement, contains far fewer examples than the first two. Indeed, only one directly relevant example was found in the literature, although there are a number of others that apply similar methods in different contexts. The key feature of studies of this type is that they replace the electronic brains used in computer models with the human brains of experts whose experience and knowledge lend credibility to their predictions. The studies employ systematic methods for obtaining and synthesizing opinions of different experts in an effort to reach consensus judgements.

2.4 Empirical Studies

As noted in the previous section, empirical studies differ along several dimensions. However, for purposes of this review they are divided into two primary classes. The first set of studies consider the impacts of specific facilities or projects Within this set, which we term "facility-specific" studies, a further differentiation is made between investigations that focus on impacts on traffic levels, and those that consider land use impacts. The second set of studies focus on more aggregate relationships between highway supply and traffic or land use variables. Following Ruiter (1979), we term these "area studies."

2.4.1 Facility-Specific Studies

The traffic-generation impacts of at least several dozen road projects have been studied. Most of these studies follow the same general approach. Beginning before the improvement, traffic volumes along the project corridor are measured. Measurements are continued through the opening of the project and some period thereafter. Additionally, in most of these studies some attempt is made to infer how traffic volumes would have evolved in the absence of the improvement. The difference between the observed growth and the growth expected in the absence of the project is traffic generated by the project. Figure 2-1 summarizes results from several of these studies, plotting estimated increases in traffic on the expanded roadway or corridor resulting from the expansion, as a function of time since project completion.

Studies of this general form date back at least to the 1940s. The work by Jorgenson (1947) is prototypical. Jorgenson studies traffic generated on the corridor between New York City and New Haven, Connecticut by the opening of the Merritt and Wilbur Cross Parkways. These new facilities together form a parallel route to U.S. 1, the only significant alternate route at the time of the study. To assess the traffic generated by the parkways, annual traffic counts in the corridor are tracked from several years before opening of the parkways through the decade after opening. Gasoline sales for the state of Connecticut are also tracked over this period. It is found that gasoline sales growth followed traffic growth in the corridor quite closely prior to opening of the new facilities. Consequently, gasoline sales growth after opening is used as a basis for determining what traffic would have been without the new route. Using this method, Jorgenson estimates that opening the Parkways increased traffic in the corridor 25-30 per cent.

Jorgenson's work, like most of the early studies, involved facilities primarily intercity in character. Studies involving urban facilities date at least to 1955, when the Cook County Highway Department reported on the traffic diversion and generation impacts of the Eden Expressway, which connects the city of Chicago with its northern suburbs (Mortimer, 1955). Traffic counts were taken on three screenlines, each 4-5 miles in length, passing through the expressway and several parallel routes on either side of it. These counts are compared with counts through the same screenlines taken four years earlier, prior to the opening of the expressway. Growth in total motor vehicle registrations for communities located in the Eden corridor is used as a basis for estimating what traffic growth would have been without the

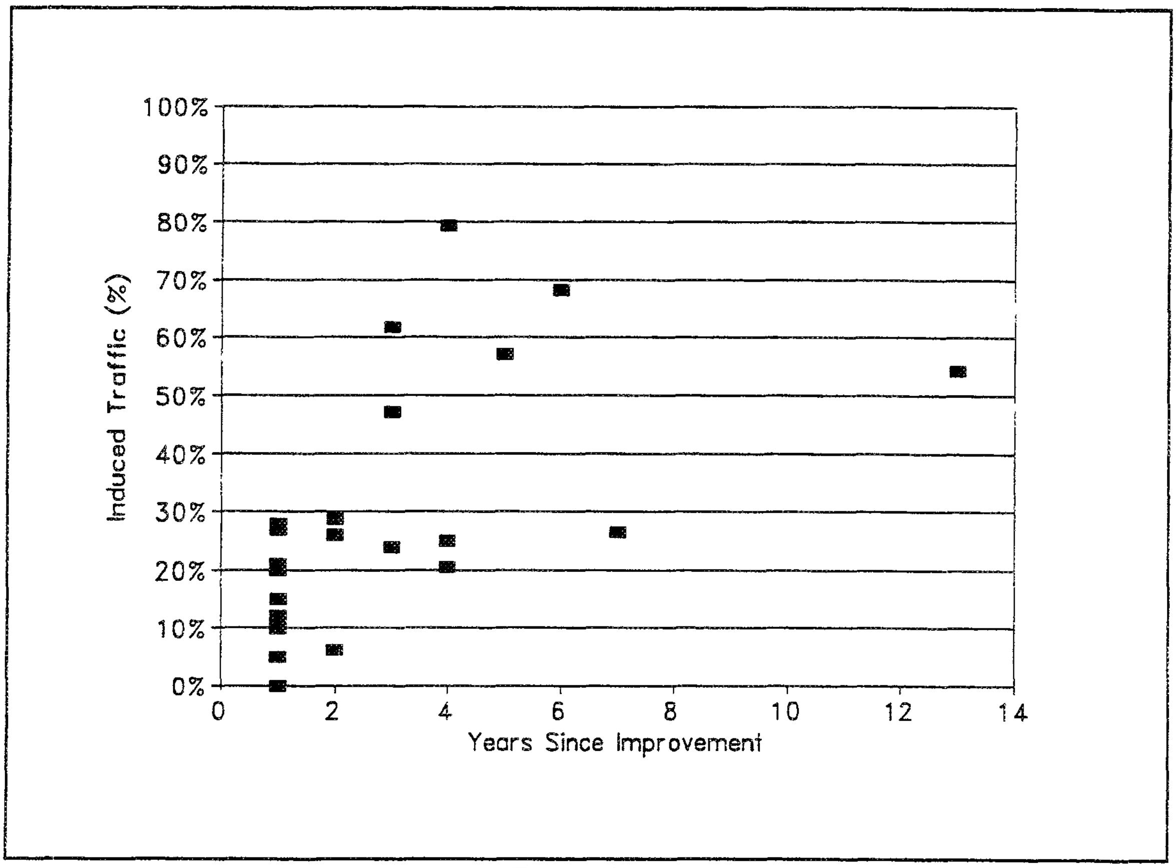

Figure 2-1.
Estimates of Induced Traffic from Road Improvements,
Various Studies

expressway. 16-hour traffic levels through the outer, middle, and inner screenlines all grew faster than the motor vehicle registrations. Based on this comparison, it appears that the Eden Expressway increased traffic passing through these screenlines by 3, 10, and 33 per cent respectively over the four year period. While the report gives considerable attention to the distinction between generated and diverted traffic, it is inconclusive as to the source of the apparent increase in corridor traffic resulting from the expressway.

Studies of traffic diversion and generation impacts of urban expressways in the Chicago area continued with the Chicago Area Transportation Study. Frye (1964a) analyzes traffic changes arising from the Dan Ryan Expressway. Traffic through a 5-mile screenline centered on the expressway increased 11 per cent in the first 4-5 months after the expressway opened (Frye does not attempt to assess expected growth in this period without the new facility). On the basis of an origin-destination survey, Frye concludes that almost all of the additional trips result from changes in route choice -- "new traffic resulting from a change of mode or change of destination appears to be too small to measure." In a study of the impact of the Eisenhower expressway, Frye (1964b) reports a 21 per cent VMT increase in the area of the expressway between 1959 and 1961, as compared with a 14 per cent increase in three control areas. Again, route diversion from outside the study area, and to a lesser extent route lengthening in order to access the expressway, are argued to be the primary sources of the additional traffic.

Yager (1973) studies peak traffic levels on a corridor through the Canadian city of Kitchener, Ontario, after a major bottleneck was removed. Corridor traffic increased roughly 10 per cent one month after the improvement The increased traffic is attributed to diversion. Yager finds that response to the roadway change was quite rapid, with most users deciding upon their preferred routes within one week of the project opening.

Holder and Stover (1972) examine the traffic generation impacts of eight urban highway projects in Texas. They are particularly interested in the level of "induced traffic", which they define as "new trips made because of added convenience," as opposed to trips diverted from other routes or modes, or created as a result of factors such as population growth, land use change, or socio-economic change. Lacking adequate data to measure induced traffic. they instead measure "apparent induced traffic," which they infer from comparing corridor traffic growth after project opening with either regional trends or corridor growth prior to project completion. Estimates of apparent induced traffic range from 5 and 21 per cent in six of the eight projects studied. No evidence of traffic inducement is found in the other two cases, a result the authors attribute to the availability of other routes offering comparable travel times in the project corridors

Pells (1989) reports on the traffic generation impacts of several roadway improvements in the London, U.K. area. A portion of Westway, a radial route in West London, was converted to a grade separated, elevated highway. This apparently caused daily traffic in the Westway "corridor" (it is not clear what if any other arteries this includes) to increase 12 per cent, and morning peak traffic 19 per cent. within 2-3 months, based on a comparison with a control corridor centered on a route (Finchley road) which approaches London from the north. The greater increase in the peak period is attributed to mode shifting from rail, but evidence for this is not presented. Comparisons with the same control corridor suggest that the improvement had stimulated an 80 per cent daily traffic increase in the Westway corridor after five years, after which traffic growth on both corridors equalized

A second project discussed by Pells is the A316, a radial route in Southwest London that was widened from four to six lanes The M4, a West London route, is used as a control After six years, both peak and daily traffic in the A316 corridor had increased about 25 per cent more than traffic in the M4 corridor. Unlike Westway, the disparity in traffic growth between the expanded and control corridors persisted for several years thereafter After nine years, peak and daily traffic on the A316 had respectively increased 56 per cent and 34 per cent more than traffic on the M4. (During this latter period, however, traffic on the M4 declined, suggesting the presence of confounding factors.) Land development in West London, particularly near Heathrow Airport, is asserted to be the primary stimulus for additional traffic in the A316 corridor, but it is not clear whether the A316 improvement contributed to this development.

Pells also presents evidence concerning the impact of adding an additional tunnel at Blackwall, doubling the capacity of this East London crossing of the Thames. Applying the same methodology used in the previous two cases, after four years tunnel traffic is estimated to be 65 per cent higher, on both a daily and peak hour basis, as a result of the capacity increase. After 14 years, the increases are estimated at 89 per cent and 98 per cent for daily and peak traffic respectively Insofar as transit service in this corridor is limited, it is concluded that the additional trips represent a net addition to cross-Thames travel, believed to have been suppressed previously due to limited capacity.

Finally, Pells describes one additional study based on driver interviews The survey asked drivers on the newly opened Rochester Way Relief Road about the effect of the new facility on the particular trip they were making when they received the questionnaire. Of 184 drivers responding (response rate 24 per cent) to the survey, the vast majority indicated that they had merely shifted their route. Among the exceptions, 6 reported a change in trip destination, 5 a mode shift, and 18 that they make the trip more frequently. These results suggest that, at the time of the survey, between 10 and 15 per cent of trips on the road represented net additions to regional travel.

Addison (1990) compares actual and forecast traffic on several expanded facilities in northern California. Although such comparisons do not directly measure induced traffic, they are relevant because the forecasts often overlook traffic-inducing effects

The first project Addison considers involved expansion and construction of interchanges on I-680 in eastern Contra Costa county, completed in 1985. 1986 ramp counts are compared with forecasts for the year 2005, prepared in 1983. While traffic levels on most ramps were, as expected, well below 2005 forecasts, 7 out of 18 ramps already had counts in excess of the forecasts.

The second project considered by Addison is an upgrade of a 12-mile section of Route 101 in San Clara county from an arterial to a grade-separated highway, completed in 1984. Daily traffic levels on the improved section observed in 1985 exceeded 1995 forecasts by 21 per cent, while traffic in the peak was 25 to 30 per cent greater

In the third project reported by Addison, another section of Route 101, south of the one considered above, was widened from six to eight lanes in 1988 The only post-improvement traffic counts available were for one freeway interchange along this section Morning peak counts taken in 1989 exceed 1995 predictions for all four off-ramps and off-loops, but for none of the entrance facilities.

Addison reports one case in which forecasts are likely to exceed actual counts. The Roseville Bypass, opened in 1987, routes through traffic around the signalized highway through the Sacramento suburb for which it is named. Counts on the bypass taken in 1989 are found to be 30 per cent less than what is forecast for 1991. This apparent overprediction probably results from the failure of anticipated industrial development to materialize in the Roseville area.

One way in which road improvements may stimulate traffic is by attracting traffic-generating land uses to their vicinity. Babcock and Khasnabis (1971) investigate land use changes near interchanges of controlled access highways in North Carolina In rural areas, little development other than roadway oriented businesses such as service stations occurred. In the 76 suburban interchanges studied, 85 industrial developments and 65 retail developments occurred, with locations near larger cities the most likely sites. The 40 urban interchanges were more intensively developed, with 61 industrial developments, 64 retail outlets and shopping centers, 26 office developments, as well as a number of multi-family housing developments Interchanges along circumferential highways with previously undeveloped land are found to be particularly attractive for shopping centers and office developments. Multi-family housing developments are observed near urban interchanges where the prior land use was predominantly residential.

The impact of capacity increases to existing facilities, as opposed to new facilities, on land use is addressed by Chui et al. (1983). Focussing on census tracts in the vicinity of expanded facilities, this study attempted to develop statistical relationships between the proportion of land developed for different uses (single family residential, multi-family residential, commercial/industrial, governmental, and streets and roads) and the stage of the expansion project (before, during, and after). The data set is based on 18 tracts in Texas metropolitan areas. No statistically significant relationships between the pace of land development and the completion of expansions projects are found. The small number of observations upon which the analysis is based, combined with the large number of other factors which must be controlled for, limit the reliability of these results.

Payne-Maxie Consultants (1980) study the impacts of beltways on urban development in U.S. cities. In one part of the study, impacts of the beltways are assessed through case studies involving interviews with local informants and review of pertinent data. Four types of development -- housing, retail/commercial, office, and industrial -- are considered.

The most consistent beltway impact on housing is the attraction of multi-family housing development to the beltway corridor, mainly for the visibility and accessibility afforded by such a location. The impact is seen as redistributive, drawing complexes which would otherwise have located closer to downtown areas. In a few cases, the beltway is also believed to have encouraged a low density, dispersed pattern of single family residential development, but for the most part this influence is considered slight in comparison with other factors contributing to dispersal.

The beltways are found to have influenced the specific locations of some retail centers in most of the case study cities, but played only a minor role in shifting retail activity from downtown to the suburbs. Rather, such a shift, if it occurred at all, derived from retailers following the suburban population In most of the cities, fewer than half of the shopping centers were located in the beltway corridor.

Suburban office development does, however, appear to have been spurred by the beltways. In several of the cities, there is evidence of a "one-time" spurt of office development in the beltway corridor in the first few years after the opening of the facility. The degree to which suburban office growth came at the expense of downtown areas varied In Atlanta, for example, it is estimated that between 7 and 9 thousand white collar jobs migrated from downtown as a result of the beltway. In other cases, however, the office development attracted to the beltway appears to have come from other suburban areas instead of downtown

In several cases, the beltways also attracted industrial development, as evidenced by the large share of such development occurring in the beltway corridors. In some instances, most notably Columbus, Ohio, the large supply of accessible land created by the beltway made the region more attractive to warehousing and distribution industries. In other cases, such as Atlanta and Minneapolis, the beltway is believed to have encouraged a shift of blue collar jobs out of the central city. Other factors, such as the obsolescence of downtown facilities, urban renewal, and desire of suburbs to increase their tax bases, are also important in contributing to such shifts, however. Radial routes have proved to be equally if not more attractive draws to industrial development.

2.4.2 Area Studies

In area studies, the unit of observation is shifted from specific roadway facilities or corridors to some larger areal unit, such as cities, states, or even countries. Travel characteristics in the unit are related to aggregate transportation demand and supply factors, through multiple regression techniques. A summary of area studies dealing with the relation between road supply and vehicle travel is presented in Table 2-1.

Table 2-1 provides estimates of the elasticity of traffic with respect to road supply from the various studies. The elasticity concept is used extensively throughout our study. It is defined as the per cent difference in one variable resulting from a 1 per cent difference in another. Suppose, for example, a change in an independent variable from X to X+ΔX leads to a change in a dependent variable from Y to Y+ΔY. One way to calculate the elasticity in this case is by simple division:

$$\epsilon_{XY} = \frac{\Delta X/X}{\Delta Y/Y}$$

This quantity is known as the arc elasticity. One drawback to the arc elasticity is that it is asymmetric: the elasticity calculated from a change in X to X+Δ and Y to Y+ΔY is generally not the same as that calculated when X+Δ goes to X and Y+Δ goes to Y. An elasticity that does not have this problem is the point elasticity, given by:

$$\epsilon_{YX} = \frac{\log(Y+\Delta Y)-\log(Y)}{\log(X+\Delta X)-\log(X)} = \frac{\Delta\log(Y)}{\Delta\log(X)}$$

If ΔX and ΔY are small relative to X and Y, or if the elasticity is close to 1 or -1, then the point and arc elasticities are nearly equal, but they diverge otherwise In light of the symmetry property of the point elasticity, we normally use it for calculating elasticities in this report.

The first area studies of the relationship between traffic and road supply were in the early 1970s, when there was interest in developing macroscopic techniques to support multi-regional transportation planning. For example, Kassoff and Gendell (1972) present relationships between urban area VMT per capita and roadway supply per capita for different urban area size classes, based on U.S. observations. They use a "system supply index" for the roadway supply variable. The index is defined as:

Table 2-1.
Elasticities for Vehicular Travel in Urban Areas

SOURCE	SUPPLY SIDE VARIABLE	ESTIMATED ELASTICITY	COMMENTS
Kassoff and Gendell (1972)	"System Supply Index" based on route-miles per capita.	below 0.58	Calculated from Figure 9 of reference. See text.
Koppelman (1972)	Lane-miles of highway.	0.13	Calculated from series of regression equations estimated from cross-sectional data.
Payne-Maxie (1980)	Route-miles of beltway.	0.12	Calculated from regression results based on cross-sectional data.
	Route-miles of freeway other than beltway.	0.10	
	Total route-miles of freeway	0.22	
Burright (1984)	Time cost of travel (estimated from average bus speed).	-0.27 (short-run) -0.51 (long-run)	Two-stage least squares regression Urbanized land area held constant in short-run case
Newman (1989)	Meters of road per capita.	0.70	Comparison of most and least energy-efficient cities.

$$SSI = 100000 \cdot \frac{5 \cdot freeway\ miles + arterial\ miles}{population}$$

Kassoff and Gendell report that as the SSI goes from 75 or less to 150 or more, VMT per capita increases roughly 50 per cent. An elasticity cannot be inferred from this result, although a value of 0.58 is evidently an upper bound.[1] The method of developing the relationship between SSI and VMT was not reported, but it appears to be based on graphical analysis, stratified by urban area size category.

Koppelman (1972), using about 20 cities for which detailed data were available, estimates a series of equations relating trip making and mode choice to transportation supply characteristics. The elasticities from the different equations are combined to estimate a elasticity of VMT with respect to highway lane-miles of 0.13 The standard error for this result is not reported, but insofar as it was developed from a series of estimated regression coefficients, each with a considerable standard error in its own right, the elasticity standard error must be quite large.

Payne-Maxie et al. (1980), in their previously cited study of beltway impacts, developed a regression equation relating daily VMT per capita to beltway and non-beltway freeway route mileage. The estimates are based on 1975 data for a cross-section of 54 metropolitan regions located in the U.S. It is estimated that one additional mile of beltway generates 85 additional daily VMT per thousand population, while an additional mile of other freeway induces 18 additional daily VMT per thousand population. Both coefficients are significant at the .05 level, and imply VMT elasticities with respect to beltway and non-beltway mileage if 0.12 and 0.10 respectively at the mean VMT per capita and mileage values.[2] The elasticity of VMT per capita

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[1] Assuming the SSI increases from 75 to 150, we calculate the point elasticity as

$$\epsilon_{YX} = \frac{\log(1.5) - \log(1)}{\log(150) - \log(75)} = 0.58$$

[2] In this case, the elasticity is calculated from the results of a linear regression If we have a relationship Y=A+BX, than the point elasticity at the mean values of X and Y is

$$\epsilon_{YX} = \frac{\Delta Y}{\Delta X} \cdot \frac{\bar{X}}{\bar{Y}} = B \cdot \frac{\bar{X}}{\bar{Y}}$$

with respect to total freeway miles is the sum of the beltway and non-beltway elasticities: 0.22.

Burright (1984) estimates a model in which private vehicle miles per household, bus trips per household, and urbanized land area are treated as endogenous variables, and modelled as a simultaneous system using two-stage least squares. Roadway supply is not explicitly included as an explanator; rather the time cost of travel, estimated as the reciprocal of the average transit bus speed, is used. Using a panel data set consisting of two years of observations (1968 and 1970) for 27 urban areas, Burright estimates an elasticity for private vehicle miles with respect to travel time cost of -0.27 when urbanized land area is held constant, and -0.51 when the indirect effects from urbanized land area changes are taken into account. Like Koppelman, Burright does not report standard errors for these results, so their precision cannot be assessed.

More recent area studies have been motivated by energy conservation and environmental issues. Newman (1989) analyzes travel and land use characteristics of 32 cities, with the intention of showing that cities with the highest service levels for roadway traffic (and therefore the most energy efficient traffic) also have the highest levels of automobile use (and therefore the least energy efficient transportation). Their cluster analysis yields five groups of cities, with average meters of road per capita ranging from 8.8 to 1.1, and average car passenger kilometers per capita ranging form 12.8 thousand to 3.0 thousand. Comparing the groups on either extreme, and assuming (implausibly) that the entire difference in car travel can be attributed directly or indirectly to the difference in road supply, an elasticity of 0.70 is obtained.

The area studies above produce a wide disparity in estimates of the sensitivity of VMT to roadway supply, ranging from 0.13 in the case of Koppelman (1972) to 0.70 for Newman (1989). One might conclude on this basis that area studies are not very useful, but an equally defensible interpretation is that the work to date has suffered from methodological shortcomings, and limited data sets. Koppelman considers only 20 cities, while Newman does not perform the multivariate analysis required to isolate the effect of roadway supply. Further, all of the studies are based on cross-sectional data only. When only cross-sectional data are used, there is no information concerning the actual response of a given area to a change in its transportation system, even though this is precisely the matter such models are intended to elucidate. There is also a strong possibility that cross-sectional analyses will be biased by the problem of omitted variables. That is, road supply may be correlated with some variable excluded from the model that also affects traffic, in which case the traffic effects of the excluded variable will be mistakenly attributed to road supply.

2.5 Model-Based Studies

As mentioned above, model-based studies can be divided into two categories, according to the type of model employed. One set of studies uses conventional regional transportation models in which land use variables are defined exogenously, while the second set is based upon more comprehensive models in which activity locations are predicted rather than assumed.

2.5.1 Studies based of Regional Transport Models

There has been a vast amount of research involving the development and use of urban transportation planning models. In principle, these models offer a means of assessing the impact of any given road improvement (or set thereof) on vehicular travel. In practice, this impact is not adequately assessed in most cases, because of failure to adequately address feedback effects. In particular, effects of a roadway capacity addition on mode split, trip distribution, trip generation, and land use patterns are generally neglected. When used in this way, transportation models assume away the impacts of roadway capacity expansion of primary importance in assessing their effect on regional VMT

Thus, of the countless planning studies in which regional transport models are used to assess the impacts of roadway improvements, only a handful are of relevance here. Beardwood and Elliot (1985) report on several runs of the STEM model, which was used to predict morning peak period travel in London U.K. under several different roadway supply scenarios. Mode split, traffic assignment, and trips redistribution effects are considered. A capacity increase on the North Circular Road, London's inner beltway, is predicted to increase regional travel 1 per cent, with increases in certain burroughs exceeding 5 per cent. An additional Thames crossing in East London increases northbound river crossings 24 per cent in the morning peak. absorbing virtually all the additional river crossing capacity the crossing provides. Impacts of the quantity of regional travel are not reported for this change, however.

The most careful and systematic effort to use transportation planning models to predict the impact of road capacity expansion on vehicle travel is probably the work of Ruiter et al. (1979). Their work is notable in three respects. First, their modelling approach is designed to capture trip generation, as well as mode split and trip distribution, impacts. Shifting of trips between peak and off-peak periods is addressed as well. Second, they pay considerable attention to the matter of model validation (although we will question their interpretation of the validation results below) Third, they report summary measures of traffic sensitivity to roadway supply change, such as the elasticity of VMT with respect to lane-miles

Ruiter et al consider two projects involving California Route 24, a freeway linking Oakland with eastern Contra Costa country The first project involved extending the freeway from Contra Costa county into Oakland. Five miles of route and 69 lane-miles (including ramps) were included in this project. In the second project, 13 miles of freeway were expanded by one or two lanes in each direction, yielding 50 additional lane-miles.

The researchers used a state-of-the-art transportation model which they applied to the entire nine-country Bay Area Running the model with and without the first project, they found that the 69 additional lane-miles, which represented a 0.88 per cent increase in Bay Area road capacity, resulted in an increase in daily VMT of 187 thousand, or 0.33 per cent. The elasticity of daily VMT with respect to road capacity is thus 0.38 The regional VMT increase in the peak-hour was found to be 31 thousand, yielding a peak-hour elasticity of 0.56. In the Route 24 corridor itself, the increase was 62 thousand, half of which represented redistribution from elsewhere in the region.

The second project differed from the first it that it was a widening of an existing facility rather than an entirely new one This appeared to substantially alter the VMT impact. While the peak period increase was equivalent in magnitude (26 thousand) and implied elasticity (0.64) to that generated by the first project, the daily VMT was found to <u>decrease</u> very slightly (3 thousand). Two explanations for this unexpected result are offered. First, the second improvement offers no improvement in level of service during the off-peak period. Second, the greater auto use for peak period work trips reduces the availability of autos for off-peak trips. In other words, the extra VMT generated by additional auto trips by commuters is more than counteracted by the loss of VMT from depriving other household members access to autos.

The credibility of these results hinges on the validity of the model. As noted, Ruiter et al. are unusually scrupulous in their efforts at validation At the regional level, person-trip and mode share results are within 1-2 per cent of observed values. Comparison of predicted traffic volumes and traffic counts on road links in the vicinity of the project indicate an average unsigned difference of 10 per cent. The researchers also attempt a more rigorous form of validation, in which they compare model predictions of link flows in the no-project scenario with flows estimated based on extrapolation of pre-project trends to the analysis year The results of this exercise are far less encouraging: the median unsigned difference between model forecasts and projected counts is 67 per cent, while the projected count total for the corridor is 41 per cent less than the model forecast. Thus, while the model does an adequate job of predicting baseline conditions, it appears considerably less satisfactory in predicting how conditions would be different in the absence of a particular road improvement. Yet these are exactly the predictions upon which issues of traffic generation hinge.

2.5.2 Studies based on Transportation/Land Use Models

All of the modelling efforts discussed in the previous section assume land use variables to be exogenous. Consequently, they fail to capture impacts of transport system changes on land use. Insofar as such land use impacts will in turn affect urban travel demand, this may be an important deficiency.

Efforts to model land use in urban regions have taken many different forms over the past three decades (Small and Berechman, 1987). Two seminal models, the Alonso-Wingo monocentric model and the Lowry model, appeared in the early 1960s. In the monocentric model, households cluster around a downtown area where all employment is located Households are willing to pay more for a housing location nearer the employment center in order to reduce commuting costs This, in turn, drives up land prices, forcing households to tradeoff housing consumption, housing cost, and commuting cost Further, as land price increases, housing suppliers are encouraged to substitute capital -- in the form of higher building costs -- for land, and therefore build taller structures. The monocentric model thus results in a three-dimensional city with taller structures nearer the city center.

Transportation supply is represented by a single parameter -- the commuting cost per unit distance -- in the monocentric model. If transport is improved, this cost goes down, and households are generally willing to locate further from the employment center. Near the center, this has the effect of reducing land prices and thus development intensity. On the other hand, land prices and development intensities increase in outlying areas Through this mechanism, improved transport generates increased regional travel in the form of greater commuting distances.

The monocentric model, while an enormous simplification of actual urban areas, has been highly influential. Its simple and powerful geometric imagery has, rightly or wrongly, guided the thinking of a generation of urban economists. At the same time, it is recognized that the model is not suitable for estimating impacts of incremental changes in the transportation network. Further, the suburbanization of employment over the past century, particularly the creation of suburban office centers in more recent years, as well as rapid growth in non-work related tripmaking, has made the downtown commute an ever smaller part of the overall urban travel market. Consequently, the direct relevance of the monocentric model to contemporary cities is quite limited. Nonetheless the tradeoffs between land rent, land use intensity, and transportation cost continue to play an important role in shaping urban form.

In contrast to the monocentric model, models designed for application to real world cities are computer based, and can be used to assess the impacts of specific scenarios involving transportation supply, land use policies, regional growth, and other factors. These models are diverse: according to Small and Berechman (1987) they vary with respect to behavioral basis, time scale, endogenous sectors, externalities, and solution method. The behavioral basis may be microeconomic, in which case actors are assumed to maximize utility or profit, or based on physical analogies such as gravity and entropy. The time scale may be either a single point in time or a period of time over which changes in the region are predicted. The endogenous sectors may include employment, residential population, and housing, all of which may be divided into several different categories. Lastly, solution methods include iteration, simulation, and mathematical programming.

Of fundamental importance to this study is the manner in which transportation is incorporated into the models. In most of the models, the location of activities is affected by transportation supply through relationships leading to location outcomes with comparatively low total transportation costs, and which imply that reductions in transport costs per unit distance result in greater travel distances. The majority of these models, however, fail to make transport costs endogenous, or to consider alternative modes of transport.

Our primary interest is with those models that do endogenize transport cost. The Integrated Transportation Land use Package (ITLUP) is a well known example (Putman, 1980). ITLUP begins by distributing an exogenously forecast level of basic employment throughout a region. From this, non-basic employment and residences are allocated, using a gravity model and based on an initial set of zonal travel time matrices From these results, regional trip tables are created and loaded onto the transportation network. The loaded network is used to update travel times, and the non-basic employment and residence allocation repeated Iteration continues until convergence is achieved.

The ITLUP model was applied to the San Francisco Bay Area to predict the consequences of a number of policy scenarios (Putman, 1980, 1983). One set of runs involved hypothetical changes in travel time on the Bay and Golden Gate Bridges, as could result from changing the capacity of these facilities. Results of the runs are reported only in a qualitative way. A travel time reduction on these bridges was found to increase population in the northern and eastern inner suburbs that the bridges link to San Francisco, and a reduction in the population of San Francisco itself. Thus "the concern of Marin County that bridge improvements would make more difficult the control of land use in the county seems to be strongly supported by these results (Putman, 1980, p. 86)." On the other hand, expanding bridge capacity appears to reduce regional VMT, with average trip lengths decreasing for the inner suburbs where growth is induced, and remaining unchanged elsewhere. This somewhat surprising result seems to derive from the bridge improvements encouraging relatively short distance, but previously heavily congested, commutes to San Francisco from the north and east.

Although popular, the ITLUP model has several weaknesses. First, the land use component lacks a strong theoretical base, especially in its failure to reflect market mechanisms (i.e land and housing prices) in determining location outcomes. Second, its transportation component is unimodal, thereby precluding analysis of transport supply changes on mode choice or the impacts on land use from accessibility afforded by modes other than the automobile.

Several other transportation/land use models, all of European or Japanese origin, improve on one or both of these shortcomings. Four such models have recently been used in a comparative study by the International Study Group on Land use/Transport Interactions (ISGLUTI).

Two components of the ISGLUTI study involve comparisons of impacts of specific scenarios both to assess the consistency of predictions of the different models and to compare impacts of similar changes in different types of cities. In one component, three different models were applied to the same city -- Dortmund, Germany (Wegener et al.. 1990). Of the several dozen policy scenarios considered, the most relevant involve systemwide changes in car and public transport speeds. Table 2-2 summarizes the impacts of scenarios in which a 20 per cent speed increase is assumed for both modes, and a 20 per cent increase in public transport is accompanied by a 20 per cent decrease in car speeds. Under the former scenario, both average trip distances and public transport use increase. The models diverge, however, with respect to the magnitude of the latter impact and, by extension, with respect to whether the speed change would increase or reduce the total amount of regional travel. Under the latter scenario, in which car speeds are reduced, there is, as expected, as stronger shift toward public transport, although the magnitude of the predicted impact again varies widely. Larger, but still modest, impacts on central city employment, average trip distance, and car ownership are also predicted under the latter scenario.

Although the above results reflect the variation in predicted impacts stemming from differences among models, they are based on just one city. Differences in impacts in different cities were assessed in another part of the ISGLUTI study (Webster, 1991). The cities involved considered are Dortmund, Leeds, Tokyo, and Bilbao (Spain) Four different models were applied, but not every model was applied to every city. Results thus reflect both differences between models and between cities. The policy tests were similar to those used in the Dortmund study Table 2-3 summarizes results for the two policy scenarios involving systemwide speed changes In general, the results suggest that other cities are somewhat less sensitive to the speed changes than Dortmund. The apparent reason is that Dortmund is a lower density, more auto-oriented city than the other three.

As in the Dortmund study, the four-city study shows considerable variation in the predicted magnitudes of different impacts relative to the mean of the predictions. The

Table 2-2.
Predicted Impacts of Speed Changes in Dortmund, Germany

VARIABLE	CHANGE	20 PER CENT SPEED INCREASE--CARS AND PUBLIC TRANSPORT	20 PER CENT DECREASE IN CAR SPEEDS AND 20 PER CENT INCREASE IN PUBLIC TRANSPORT SPEEDS
Proportion of Employment in Central City	Maximum	-1%	+3%
	Minimum	0%	-0.5%
	Mean	-0.5%	+1%
Average Trip Distance	Maximum	+6%	0%
	Minimum	+3%	-8%
	Mean	+5%	-3%
Share of Trips by Public Transport	Maximum	+16%	+24%
	Minimum	0%	+4%
	Mean	+4%	+19%
Change in Car Ownership	Maximum	0%	0%
	Minimum	0%	-2%
	Mean	0%	-1%

Table 2-3.
Predicted Impacts of Speed Changes in Bilbao, Dortmund, Leeds, and Tokyo

VARIABLE	CHANGE	20 PER CENT SPEED INCREASE--CARS AND PUBLIC TRANSPORT	20 PER CENT DECREASE IN CAR SPEEDS AND 20 PER CENT INCREASE IN PUBLIC TRANSPORT SPEEDS
Average Trip Distance	Maximum	+5%	0%
	Minimum	+2%	-3%
	Mean	+3%	-1%
Share of Trips by Pubic Transport	Maximum	+11%	+18%
	Minimum	-1%	+3%
	Mean	+4%	+9%

conclusiveness of the results depends on the question of interest. One can safely conclude from these results that the elasticity of trip distance with respect to travel speed is less than one One the other hand, the effect of the 20 per cent increase in all travel speeds on total regional travel is ambiguous, with greater trip distances canceling mode shifts toward public transport in some models and cities, but not in others. Given such uncertainty concerning the impact of a systemwide travel speed change, the effect of any specific incremental change in the transportation network must be seen as beyond the resolution of existing transportation/land use models.

2.6 Studies based on Expert Opinion

As explained earlier, studies based on expert opinion replace explicit analysis with the informed judgement of individuals believed to have a high level of knowledge and experience with the system of interest The only known study employing this approach in the context of urban transportation planning is that by Cavalli-Sforza and Ortolano (1983), who use the Delphi method to project the land use and urban travel implications of three alternative transportation improvement programs in Santa Clara County, California.

In the Delphi method, a panel of experts are asked to make a set of predictions concerning some unknown relationships of future events, based on a common set of assumptions and information. After a round of predictions is completed, each participant is given information concerning the responses of other panel members, and asked to make a new set of predictions The procedure continues for several iterations, after which predictions are expected to converge or at least stabilize.

In the Cavalli-Sforza and Ortolano study, a panel of 12 individuals -- including academicians, planners, local officials, business people, and neighborhood activists -- were asked to predict selected land use and travel variables for the year 1990 and 2000 under three alternative transportation programs, which emphasized respectively, auto, bus, and rail improvements. Three iterations were completed, after which results had largely stabilized, although a considerable range in predictions remained. Panelists appeared to view the auto and bus programs, both of which involved substantial highway improvements, as having roughly the same land use implications. As compared with the rail alternative, these include slightly (between

2 and 8 per cent) lower levels of study area population and employment, with the central San Jose area primarily affected, a higher proportion of single family units in the housing stock (62 versus 58 per cent), a slightly higher proportion of commuters from outside the study area (48 versus 46 per cent; in this case, the results for the bus and rail alternatives were quite similar), and a higher fraction of drive-alone commute trips (78 versus 68 per cent).

2.7 Summary and Conclusions

This chapter has reviewed previous studies concerning the relationship between roadway supply and roadway traffic in urban areas. A broad range of approaches -- from before-after analyses, to cross-sectional area studies, to regional models, to case studies, to the gathering of expert opinion -- have been identified The variety of methods points to the difficulty of the issue, a consequence of the diffuseness of the impacts, the time that may be required for them to appear, and the role of other traffic-influencing factors.

Before-after studies of the impact of specific road projects have found substantial traffic increases beginning in the first few years or months after the completion of improvements. Few studies have attempted to follow impacts beyond this initial period Those that have suggest accelerated traffic growth continuing for from five to over 10 years after project completion The changes in traffic resulting from improvements varies widely, from under 10 per cent to close to 100 per cent. This range is hardly surprising in light of the differences in the magnitudes of the improvements and the severity of congestion prior to them. It is unfortunate, however, that these studies do not report results on a more comparable basis -- in terms of elasticity, for example. Furthermore, these studies do not attempt to identify the sources of additional traffic -- mode shift, route diversion, etc. -- in more than an impressionistic manner. Therefore, the question of whether, or how much of, the increased traffic represents a net addition at the regional level is left unanswered.

Empirical studies of the land use impacts of roadway improvements are subject to similar criticisms. As before, in the absence of impact measures that can be compared across cases, generalizations from these studies can go little beyond the stage of identifying the nature of the impacts and roughly ordering their importance. Also, while it is easy to observe land use changes in an improved corridor, it is difficult to assess what would have happened in the absence of the improvement. This is a problem even when the improvement is a major new facility, as was the case in the studies cited above. The impacts of an incremental capacity addition would be even harder to discern with this approach.

Empirical studies at the area level have found statistically significant relationships between aggregate roadway supply and aggregate traffic Unlike the before-after corridor studies, these yield a comparable metric: the elasticity of traffic with respect to capacity. The area-wide studies do not, unfortunately, yield consistent estimates for this parameter, with their range extending from 0.1 to 0.7. This divergence may result from the use of cross-sectional analysis in these studies. Urban areas vary along many dimensions, and cross-sectional results will vary depending upon which factors are controlled for. This choice is a difficult one, because it requires a judgement of whether a given factor represents a separate influence, or is an intermediate variable (that is, one which is itself determined by roadway supply) A further source of uncertainty in these studies is the possibility of simultaneity bias resulting from the fact that roadway supply is itself influenced by demand

Regional models represent a third approach to studying relationships between roadway supply and traffic. By modelling in a detailed way the transportation (or transportation/land use) system, these models can simulate the impacts of any given change in roadway supply on traffic throughout the system. Efforts in this area are subject to three main criticisms. First, many of the studies employ models in which potentially important linkages, such as effects on land use and trip generation, are missing. Second, the models are exceedingly difficult to validate, particularly if one goes beyond the commonly accepted but overly lenient standard of being able to replicate a baseline system. Third, modelers have developed the bulk of their attention to methodological issues, and have not by and large attempted to use their tools to establish the general relationships sought in this study. The ISGLUTI study is certainly a step forward in this regard, but is still more oriented toward comparing models than extracting generalizations from them.

Use of expert opinion, like regional models, seeks to isolate relationships between variables of interest by constructing scenarios in which other variables are held constant. This approach is motivated by the perception that many computer models require a high level of effort to use, while yielding unreliable results. While good human judgement may indeed be a superior alternative to bad computer models, it is clearly not a substitute for systematic research. Rather, expert opinion should be viewed as a pragmatic short-cut when decisions must be made and the time or resources for research are lacking.

In sum, despite considerable prior research, our knowledge and understanding of the traffic generating impacts of road capacity expansion is limited. The direct impacts of major projects can, like a strong radio signal, be readily discerned, but as the signal dissipates over space and time, it is easily lost in the "background noise" of other processes influencing urban growth and change. Researchers have tried different means -- from statistical analysis aimed at distinguishing signal from noise, to recreation of the signal in the noise-free environment of a computer model, to consultation with experts attuned to the local environment -- to deal with this problem. The outcome of these efforts is a set of interesting, but isolated and quite possibly inaccurate, readings A coherent, credible, picture has yet to emerge.

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Chapter 3:

Direct Traffic Impacts of Highway Capacity Expansion

3.1 Introduction

In this chapter, we consider the impacts of highway capacity expansion on traffic at the individual road segment level. If we add capacity to an urban highway. how does this affect the volume of traffic on that facility? As suggested in Chapter 2, there are two extreme -- and implausible -- positions on this question The first is that the volume of traffic is unaffected, so that the sole impact of the improvement is a higher level of service The second is that the road will quickly "fill up" so that level of service is unchanged, implying that the only impact of the improvement is a higher level of traffic. We have argued that the truth almost certainly lies been these two positions -- that the elasticity of traffic with respect to capacity, which we will denote ε_{qc}, is greater than 0 and less than 1

The value of ε_{qc} is of critical importance to both the environmental and economic assessment of capacity expansion. As this value approaches 1, it becomes increasingly certain that expanding the capacity of a roadway increases emissions from vehicles on that roadway, since at the limit we would have more vehicles operating under essentially the same traffic conditions. The emissions implications of a low ε_{qc} are somewhat more complex. In this case, a capacity increase will improve level of service and increase travel speeds. The impact of these changes on emissions is uncertain, since the relationship between speed and emissions rate depends on both the speed range and the pollutant being considered. Nonetheless, it is intuitively reasonable to expect that a substantial reduction in stop-and-go traffic conditions and associated accelerations and decelerations would reduce emissions.

With regard to economic assessment, it is well known that the lower the value of ε_{qc}, the greater the increase in user benefit from a capacity expansion This is illustrated in Figure 3-1. Suppose a roadway has an initial capacity such that the supply curve -- that is, the relation between user cost and traffic -- is given by S1, and that initial traffic on the facility is P1-A. Suppose now that the capacity is expanded, so that the supply curve becomes S2. If DI is the demand curve, then the increase in user benefit is given by the area P1-A-C-P2I. If, on the other

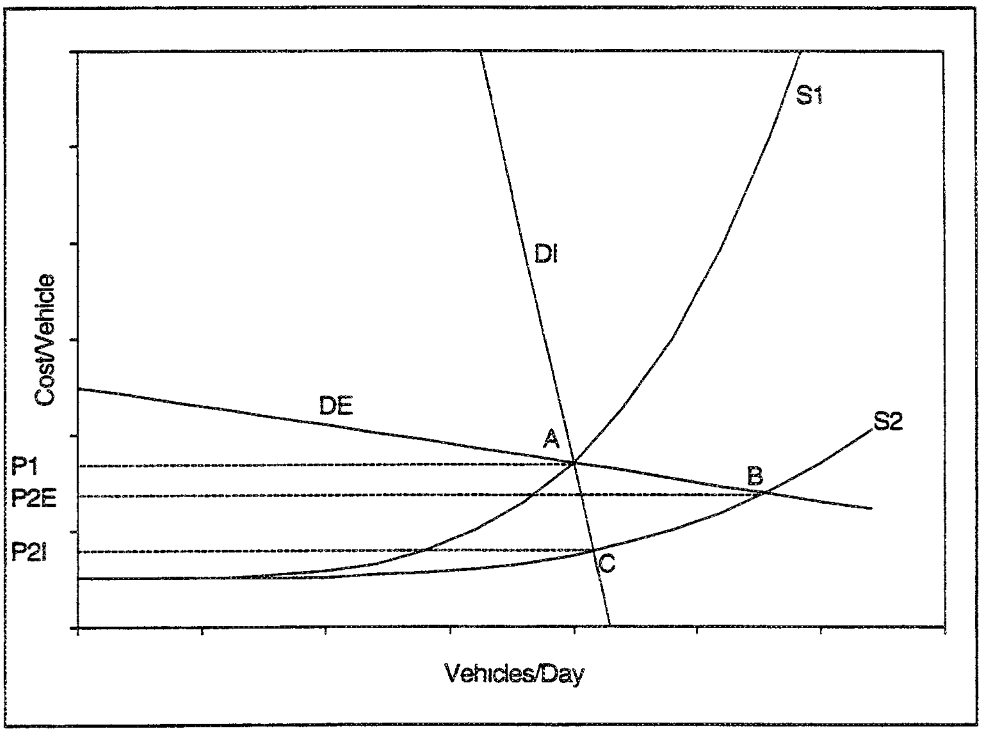

Figure 3-1.
Impact of Demand Elasticity on Highway Expansion Benefits

hand, the demand curve is the more elastic DE, the benefit is represented by the smaller area P1-A-B-P2E. In this case, most of the new capacity is absorbed by new traffic, greatly reducing the effect of the improvement on user cost.

Before attempting to measure ε_{qc}, it is important to recognize that traffic levels may respond to capacity changes gradually. As noted in Chapter 2, traffic levels derive from a host of individual choices concerning travel, activity location, and land development. While some of these choices can be modified quickly in the face of changes in transportation supply, other changes may take many years. Furthermore, the effect of a capacity increase on travel conditions may itself be delayed, particularly if there is little congestion at the time of the expansion. Thus, we expect ε_{qc} to be time dependent. To make this explicit, we will use the expression $\varepsilon_{qc}(t)$, meaning the percentage change in traffic resulting from a 1 per cent change in capacity t years after the capacity change occurs. We measure $\varepsilon_{qc}(t)$ as:

$$\epsilon_{QC}(t) = \frac{\log(Q_t^e/Q_t^{ne})}{\log(C^e/C^{ne})} \tag{3-1}$$

Where·

Q_t^e is the traffic on a roadway in year t assuming a capacity expansion t=0;
Q_t^{ne} is the traffic on the roadway in year t assuming no capacity expansion;
C^e is the capacity of the roadway after the capacity expansion;
C^{ne} is the capacity of the roadway prior to the capacity expansion.

When considering traffic inducement, it is important to appreciate the difference between before/after and cause/effect relationships. As equation 3-1 indicates, traffic inducement should be measured by comparing traffic under different capacity scenarios at a given time, rather than traffic before and after a capacity change. Since traffic growth on California highways has been nearly ubiquitous during the period of study, while capacity has been expanded on only a small fraction of the system, it is clearly inappropriate to assume that traffic on an expanded segment would have remained constant without the expansion. But while the constant traffic assumption is clearly wrong, there is no direct way to observe what the evolution of traffic on an expanded roadway would have been if the expansion had not occurred. One must instead resort to statistical methods whose results, while undoubtedly superior to the constant growth assumption, are subject to inherent error and uncertainty.

Several of the studies described in Chapter 2 examine the traffic-inducing effects of new roadway capacity, but it is difficult to extract from these general lessons applicable to the State of California. First. many of the earlier studies focus on additions to capacity that also increase travel times under free-flow conditions, such as the opening of a new grade-separated highway. Second, most previous studies are facility-specific. In addition to the obvious limits to generalizability from individual cases, there is no reason to believe that the cases studied, taken collectively, are representative of capacity expansion projects in general Finally, even if these cases are broadly representative, their impacts may not reflect what occurs in California, with its unusually high levels of automobile dependence and freeway development.

The study reported here avoids these shortcomings. First, it focusses on capacity additions to existing facilities whose impacts on free-flow travel speeds are likely to be slight or non-existent. Second, it considers a large number (18) of projects, all in California urban areas, selected in such a manner that results should be representative of capacity increases on California urban freeways in general

The study reported here is, however, limited in several respects. First, only mainline segments -- not ramps or interchanges -- are considered. Second, we do not consider how a capacity addition to one roadway segment affects traffic on other segments. Clearly, any additional traffic on the improved segment must also use other links on the roadway network as well. Further, a large proportion of the additional traffic may have diverted from other routes. These complement-substitute relationships between different links in a road network imply that if a change to one link has a substantial traffic impact on that link, other links are likely to be significantly affected as well.

The remaining sections of this chapter are organized as follows. Section 3.2 explains the methodology and models used to estimate $\varepsilon_{qc}(t)$. Section 3.3 describes the data collection and analysis methods used to estimate the models. Section 3.4 presents and discusses estimation results. Section 3.5 evaluates the accuracy of the alternative models in predicting post-expansion traffic levels. In section 3.6, estimates of traffic inducement derived from the models are compared, while conclusions are offered in Section 3.7.

3.2 Methodology

This analysis employs the counterfactual approach First, a statistical relationship between the traffic and capacity is developed for a set of road segments whose capacities have changed over time. The model is then applied under two scenarios. The first scenario assumes the capacity increases that actually occurred, while in the second -- the counterfactual -- it is assumed that these capacity expansions did not occur. The difference in predicted traffic under the two scenarios, for t years after the expansion, is an estimate of the traffic induced by the expansion in year t, which is in turn used to estimate $\varepsilon_{qc}(t)$.[1]

Two different statistical models relating traffic to capacity are used. The first model relates traffic level to total capacity. The second model relates traffic growth to unused capacity. By applying the counterfactual method using two different models (and different variants thereof), we obtain quasi-independent estimates of $\varepsilon_{qc}(t)$, based on different underlying assumptions about the nature of the relationship between road capacity and road traffic.

3.2.1 Traffic Level Model

The proposed traffic level model is:

$$Q_{it} = \alpha_i \cdot C_{it}^{\beta} \cdot SQ_t^{\gamma} \cdot e^{\lambda \frac{NC_{it}}{t^{\sigma}} + \epsilon_{it}} \tag{3-2}$$

Where:

t	is time, measured in years and such that the capacity expansion is completed at t=0;
Q_{it}	is the traffic volume on segment i in year t;
C_{it}	is the capacity of segment i in year t;
SQ_t	is the vehicle miles traveled (VMT) on the California state highway system in year t;
NC_{it}	is a variable equal to the capacity added as a fraction of total capacity for t>0 and equal to zero for t<0;
α_i	is a multiplicative factor for segment i, estimated during model calibration,

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[1] As is standard practice, the model is used to predict traffic in the capacity expansion scenario, even though data are available. This procedure eliminates the effects of any systematic tendencies of the model to under- or over-estimate traffic

$\beta, \gamma, \lambda, \sigma$	are coefficients to be estimated during model calibration;
ε_{it}	is a stochastic error term, drawn from a normal distribution with mean 0.

In this model, the effects of capacity on traffic are reflected in the coefficients β, λ, and σ. β represents the long run elasticity $\varepsilon_{qc}(\infty)$. That is, if capacity is increased by 1 per cent at time t=0, then the eventual traffic increase resulting from this change will be β per cent. However, traffic is expected to increase to this new level gradually, not immediately after the capacity is increased. λ and σ characterize this gradual adjustment process λ, which we expect to be negative, measures the magnitude of the adjustment. In particular, consider a given road under two scenarios that differ in only one respect. In one case, the road has had its current capacity for an extended period of time, long enough for traffic to adjust to its long run level, while in the other a certain fraction, X, of it current capacity has been added one year before Then the traffic in the latter scenario is predicted to be $e^{\lambda X}$ (which is less than 1 assuming λ is negative) times the traffic in the former scenario. The pace of the adjustment depends on σ. This parameter determines the rate at which the traffic level approaches the long term traffic level as the time since the capacity addition increases.

The segment-specific multiplicative factor, α_i, captures characteristics of the segment that remain constant over the period of analysis. These factors absorb purely cross-sectional variation in traffic. Suppose, for example, that there are two road segments, one of four lanes and the other of eight lanes, and that the latter consistently has twice as much traffic as the former. We should not conclude from these observations that the additional lanes "cause" the additional traffic, since it is equally possible that latter road has more lanes because planners anticipated higher traffic levels. According to the model, the traffic difference in this example could result either from a segment effect or a capacity effect. The model can distinguish these effects only when the ratio of the two roadway capacities changes over time.

The state traffic term, SQ_t, captures the effect of systemwide traffic growth. Traffic on California state highways has grown steadily over the last three decades. Growth has occurred throughout the system, not just on segments whose capacity has been expanded. The state traffic term is intended to distinguish this "background" traffic growth from traffic growth resulting from a capacity increase.

Finally, the error term, ε_{it}, is included because the proposed model is statistical in nature, so that its predictions are subject to random error. The assumptions about the form and distribution of the error term support estimation using linear regression, as discussed below.

There are many other variables that may also affect traffic on a roadway segment. However, we exclude these from the model for two reasons. First, many of the relevant variables, for example those pertaining to land use in the vicinity of the roadway, may themselves be affected by capacity (see Chapter 4). Second, obtaining the additional data would have represented a major collection effort.

The traffic level model reflects the maintained hypothesis that the estimated coefficients β, γ, λ, and σ are constant across the roadway segments studied This may not be true, since there is no inherent reason why all roadway segments, or even all California urban highway segments, should have the same demand characteristics. As will be discussed below, however, data are not sufficient to obtain reliable coefficient estimates for individual segments. The proposed model, on the other hand, can be estimated by pooling data from different segments The resulting estimates characterize the relationship between capacity and traffic for an "average" California urban highway segment,[2] but may not be very accurate for any individual segment.

The traffic level model is estimated using ordinary least squares (OLS) linear regression Taking logs of both sides of equation (3-2), we obtain

$$\log(Q_{it}) = \log(\alpha_t) + \beta\cdot\log(C_{it}) + \gamma\cdot\log(SQ_t) + \lambda\cdot\frac{NC_{it}}{(t-t_0)^{\sigma}} + \epsilon_{it} \qquad (3\text{-}3)$$

The transformed model is linear or log-linear in all coefficients except σ. We therefore assume different values for σ, and then use OLS to estimate the other coefficients. A range of plausible σ values is determined by identifying the models with the lowest predictive errors.

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[2] More precisely, the results characterize the relationship for an "average" segment that underwent a capacity expansion over the period of study

3.2.2 Traffic Growth Model

The specification for the traffic growth model is:

$$\frac{Q_{it+\Delta}}{Q_{it}} = \alpha_i \cdot \left(\frac{SQ_{t+\Delta}}{SQ_t}\right)^{\beta} \cdot \left(1 - \frac{Q_{it}}{C_{it}}\right)^{\gamma} \cdot e^{\varepsilon_{it}} \qquad (3\text{-}4)$$

Where all terms are as defined for equation 3-2 It is assumed in this model that $C_{it+\Delta}=C_{it}$ -- that capacity over the period of an individual observation is constant

According to the traffic growth model, traffic growth on a roadway segment between year t and year t+Δ depends upon the available capacity in year t, $1-Q_{it}/C_{it}$. Further, the form of the relationship is such that if $Q_{it}<<C_{it}$, then C_{it} has little impact on traffic growth, while as $Q_{it}\rightarrow C_{it}$ the sensitivity of traffic growth to capacity becomes stronger.

Like the level model, the growth model includes a segment-specific correction factor. However, this factor is expected to be less important in the growth model because differences in traffic growth among segments are less persistent over time. Therefore, we also tried a specification without segment specific multiplicative factors, that is with $\alpha_i = \alpha\ \forall i$.

The growth in state highway VMT is included to account for general traffic growth As in the traffic level model, including this term allows the effect of the "background" growth rate to be distinguished from growth resulting from high levels of available capacity.

The stochastic error term, ε_{it}, is included in the model because, like the traffic level model, the traffic growth model will not be perfectly accurate. As before, the assumptions about the distribution of this random variable are made for convenience, so that the model can be estimated using least squares regression.

The traffic growth model does not yield direct predictions of traffic level, but it can readily be used to generate such predictions. Given the traffic level in some baseline year, the traffic growth predicted by the model can be used to estimate traffic Δ years later. The traffic forecast for Δ years later can then be used to predict traffic 2Δ years later, and so on. If capacity of the roadway is increased in year 0, then beginning at 0 traffic growth will be faster than it would have been without the improvement. One can estimate $\varepsilon_{qc}(t)$ by comparing traffic forecasts for year t after the improvement under the scenarios in which a capacity increase at t=0 does and does not occur. Unlike the traffic level model, however, the traffic growth model does not include an explicit estimate for the long run elasticity, $\varepsilon_{qc}(\infty)$. Indeed. assuming the combined state traffic and segment effects yield constant positive growth, the growth model predicts that segment traffic will increase until it reaches some limiting fraction of capacity. Implicitly, therefore, the traffic growth model assumes that the long run elasticity is 1. But this may be true only in the very long run. For a reasonable planning horizon, say 20 years, the elasticity may be considerably less than 1.

The traffic growth model, like the traffic level model, is estimated using OLS. Taking logs of both sides of equation 3-4 yields:

$$\log(\frac{Q_{it+\Delta}}{Q_{it}}) = \log(\alpha_i) + \beta \cdot \log(\frac{SQ_{t+\Delta}}{SQ_t}) + \gamma \cdot \log(1 - \frac{Q_{it}}{C_{it}}) + \epsilon_{it} \tag{3-5}$$

Equation 3-5 is linear or log-linear in all parameters to be estimated.

3.3 Data

Our primary data sources are the "Traffic Volumes on California State Highways" and the "State Highway Program Financial Statements and Annual Reports", both published annually by Caltrans The former publication contains traffic counts for all roadway segments in the California State Highway system Three counts, the peak hour, peak month daily, and average daily, are given, all on a bidirectional basis. We estimate models for peak hour and average daily traffic. Annual VMT data for the state highway system as whole is also obtained from the "Traffic Volumes" publication.

The "Annual Reports" document contains a listing of all highway projects completed during the year, including a description of the project, the location, and the start and completion dates. From these listings, which go back to 1970, eighteen projects meeting several criteria were chosen All involved adding lanes to a section of state highway located in a metropolitan area and were completed prior to 1980. Furthermore, we require that the "Annual Reports" listing specify the number of lanes before and after the widening. The eighteen projects meeting these criteria are listed in Table 3-1. Six projects in the San Francisco Bay Area, nine in the Los Angeles-Long Beach Area, two in Sacramento, and one in San Diego are included. Some projects were completed in a single year, but most extended over two, three, or even four years. Initial

Table 3-1.
Capacity Expansion Projects

NO	ROUTE	COUNTY	LANES BEFORE/ AFTER	YEAR BEGIN-COMPLETE	LOCATION
1	580	ALA	4/8	70-72	Between 0 3 M W of Vasco Road, near Livermore, and 0 4 M E of Tassajara Road
2	101	MRN	6/8	71-73	Near Mill Valley, between 0 3 M S and 0 4 M N of Richardson Bay BRDG and Overhead
3	10	LA	6/8	69-72	In and near LA, Monterey Park & Alhambra Between 0 1 M W of Rt 5 and Rt 7, with connections to Rt 7
4	91	RIV	4/8	71-72	In Corona between 0 2 M E of Maple St o/c and East Grand Blvd u/c
5	91	RIV	4/6	72-73	From Spruce St to the Rt 15/60/91 Separation
6	80	SAC	4/6&8	70-73	Between 0.5 M W of Madison Ave o/c and 0 1 M W of Douglas Blvd o/c in Roseville
7	80	SAC	4/6	74-77	Between Roseville and Auburn
8	101	LA	4/8	71-74	Between Las Virgenes Canyon Rd and Medea Creek, near Agoura
9	91	RIV	4/6	73-73	In Corona, from 0 8 M W of McKinley St to 0 2 M E of Van Buren Blvd
10	80	SOL	6/8	72-73	From 1 9 M E of Rt 21, about 4 0 M W of Fairfield, to 0 6 M W of Rt 505, in Vacaville
11	5	SD	6/8	71-73	In San Diego, between 0 3 M N of Sycamore St u/c and 0 3 M S of Palm Ave
12	680	CC	4/6	72-74	From South Walnut Creek Overhead to Willow Pass Road u/c, in Concord
13	101	LA/ VEN	4/8	72-74	From Mdea Creek to Hampshire Rd, in Thousand Oaks, and at Live Oak St u/c

Table 3-1. (cont.)

NO	ROUTE	COUNTY	LANES BEFORE/AFTER	YEAR BEGIN-COMPLETE	LOCATION
14	505	SOL	2/4	72-74	From 0 6 M N of Rt 80, near Vacaville, to 0 6 M S of Yolo County Line
15	91	LA	4/8	73-76	In Carson and Compton from Main St to 0 6 M W of Alameda St
16	101	LA	6/8	74-77	In LA, from Sunset Blvd to 0 3 M N of Pilgrimage u/c
17	2	LA	6/8	73-76	In LA and Glendale, from 0 1 M N of the LA river to 0 1 M N of Rt 134
18	4	CC	2/6	74-77	In and near Concord, from 0 4 M E of Rt 242 to Willow Pass Rd

widths of the widened sections range from two to six lanes (counting both directions), while widths after completion of the project vary between four and eight lanes. Every possible combination of pre- and post-project widths is represented, with the exception that no project involves an expansion from two to eight lanes.[3] In most instances, the improved segment was of freeway grade both prior to and after the project completion, but in two cases the widening involved an upgrade to freeway grade from highway grade, while in one an expressway was upgraded to a freeway.

For each project, a time series of traffic counts is developed. The counts are obtained for the years 1,4,7,10,.. years before the widening project was begun and 1,4,7,10... years after it was completed. The three year interval is used because, although counts are published annually, traffic on any given segment is actually counted just once every three years While it is not possible to tell which of the published counts are "real," use of tri-annual count data assures that each observation is based on a count taken since the previous observation, and not merely the application of an assumed growth factor to the previous count. Excluding the years over which the widening takes place eliminates effects of the construction activity itself, which often hampers traffic and may therefore suppress demand.

Since the expansions occurred in different years, and the traffic count data are available only for the years between 1960 and 1990. the range of years for which traffic counts are available varies from segment to segment. More post-expansion counts are available for segments that were expanded earlier, while more pre-expansion data are available for the segments expanded later. Thus, as t, the number of years since the capacity expansion, increases, the number of segments for which there are traffic count data decreases. The maximum value of t for which some traffic count data are available is 19 years. Data for this year are available for just three of the 18 expanded segments.

Widening projects typically involve segments with multiple counting stations. Traffic counts at adjacent segments, however, rarely vary much Therefore, to reduce data collection,

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[3] In one project, the roadway was widened to 6 lanes on some stretches and 8 lanes on others We set the lane width after the capacity expansion to 7 in this case

counts at the stations nearest to both ends of the improved section are averaged to estimate traffic for the segment as a whole.

It is necessary to calculate a volume-capacity ratio for the traffic growth model A capacity of 2300 vehicles per lane-hr is used, rather than the more standard value of 2000 vplh. The higher value is consistent with upcoming changes in the Highway Capacity Manual, and is believed to be the best single estimate of lane capacity over the period covered in this analysis. Finally, to take account of imbalance in peak period flows, we use a directional factor of 0.66 (cited in the Highway Capacity Manual) and calculate the volume-capacity ratio in the peak direction

3.4 Results

3.4.1 Traffic Level Model

As noted above, estimation of the traffic level models involved repeated applications of OLS under different assumed values for σ. The values of this parameter that minimize the sum of squared errors (SSE) are 0.40-0.45 for the peak model and 0.2 for the daily model. In order to assess the confidence interval for these estimates, we calculated F statistics for hypotheses constraining σ to some other value, by comparing the SSE at that value with the minimum SSE. The results are plotted in Figure 3-2. The range of values yielding a F statistic below the critical value (for 95 per cent confidence) of 3.92 is from 0 1 to 2.0 for the peak hour, and from 0.04 to 0 75 for daily traffic.

Table 3-2 summarizes estimation results for the peak and daily traffic level models For both models, three sets of estimates are provided, based on three assumed values of σ covering the plausible range. (Estimates of the segment-specific multiplicative factors, α_i, are omitted, since they have no intrinsic significance.) All models yield coefficient estimates with expected signs Also, all t statistics, calculated by dividing coefficient estimates by their standard errors, have absolute values over 2 When the t statistic for a coefficient meets this criterion, we can reject with a 95 per cent level of confidence the null hypothesis that the coefficient is actually zero In other words, all of the variables in the models have statistically significant effects on traffic. Finally, all of the models yield good fits with the data, as shown by the high adjusted R^2

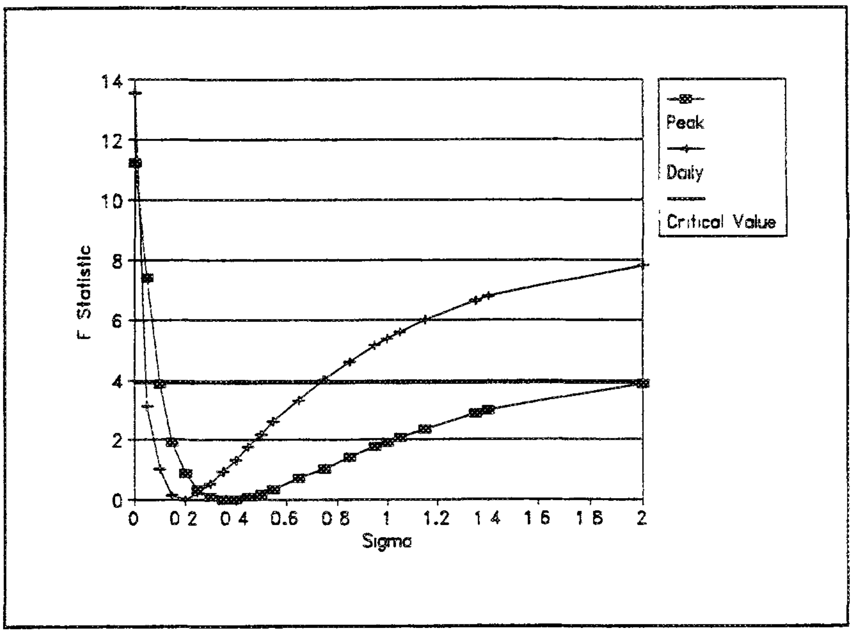

Figure 3-2
F Statistic vs Sigma, Traffic Level Model

Table 3-2.
Estimation Results, Traffic Level Models

VARIABLE (COEFFICIENT)	PEAK HOUR			DAILY		
	σ VALUE			σ VALUE		
	0.10	0.45	2.00	0.05	0.20	0.75
$\log(C_{it})$ (β)	0.98 (3.36)*	0.59 (4.46)	0.36 (3.93)	1.30 (3.70)	0.86 (4.70)	0.46 (4.53)
NC_{it}/t^{σ} (γ)	-1.16 (-2.67)	-0.64 (-3.34)	-0.33 (-2.68)	-1.59 (-3.07)	-1.03 (-3.68)	-0.44 (-3.04)
$\log[SQ_t]$ (λ)	0.87 (14.02)	0.80 (11.31)	0.84 (12.53)	1.06 (19.23)	0.96 (15.29)	0.96 (14.54)
R^2(Adjusted)	.9368	.9385	.9368	.9568	.9580	.9568

*t statistics in parentheses.

values. These statistics indicate the proportion of variation in the dependent variable explained by the model.

In the peak period, the best estimate of $\varepsilon_{qc}(\infty)$ -- which is equal to β -- is approximately 0.6, while for the daily model it is in the 0.8-0.9 range. However, since the σ values associated with these estimates are low, t must be very large before $\varepsilon_{qc}(t)$ approaches this limit. Since our data set does not include observations for $t>19$ years, these long run elasticities are of little practical significance.

Table 3-2 shows that there are strong interdependencies among β, λ, and σ. As σ increases both β and λ decrease. This suggests that the data support two somewhat contrasting interpretations. In one interpretation, the long term elasticity is high, but there is a large difference between long and short run effects (high λ), and a long adjustment process (low σ). Alternatively, the long term elasticity is lower, the difference between long and short run effects is less, and the adjustment process is more rapid These differences tend to offset each other over the first two decades after a capacity expansion, so that the different models, despite the wide variation in their coefficient values, yield estimates of $\varepsilon_{qc}(t)$ that are fairly consistent This is shown in Figure 3-3, where $\varepsilon_{qc}(t)$ is plotted against t for the three daily traffic models presented in Table 3-2, assuming a hypothetical project in which the capacity of a roadway is doubled The results for the high and mid-range σ models are very close. The $\sigma=0.05$ model yields elasticity values that are somewhat lower, but still of the same magnitude. (In any case, we will argue below that the $\sigma=0.05$ model is less credible than the other two.) One can see that as t increases beyond the plotted range, divergences become greater. Since we lack observations for such high t values, it is not surprising that the models do not agree in this domain

3.4.2 Traffic Growth Model

Table 3-3 summarizes the results for the traffic growth model. This model is fully log-linear, so estimation is straightforward. The only issue is whether to include segment-specific adjustment factors. Results with and without these factors (whose estimates, as in the traffic level model, have no intrinsic meaning and thus are not included) are therefore presented. Comparison of the SSE for the models with and without the adjustment factors provides the basis for an F test of the null hypothesis that these factors are zero. This test is rejected for the peak hour traffic

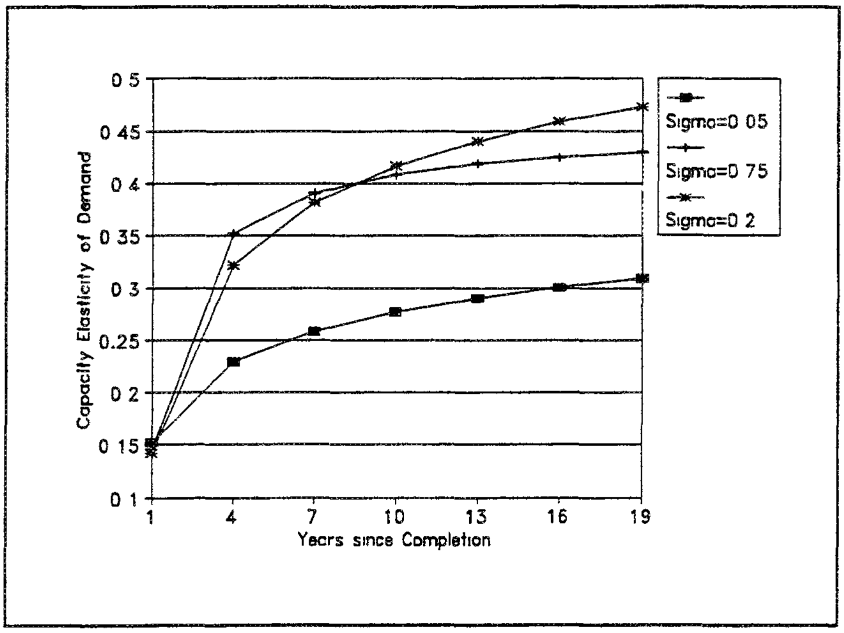

Figure 3-3.
Capacity Elasticity ($\varepsilon_{qc}(t)$) vs Years Since Completion (t), Alternative Level Models

Table 3-3.
Estimation Results, Traffic Growth Models

VARIABLE (COEFFICIENT)	PEAK HOUR		DAILY	
	WITH SEGMENT ADJUSTMENT FACTORS	WITHOUT SEGMENT ADJUSTMENTF ACTORS	WITH SEGMENT ADJUSTMENT FACTORS	WITHOUT SEGMENT ADJUSTMENT FACTORS
log(1-Qit/Cit) (γ)	0.44 (4 70)*	0.27 (4.39)	0.87 (2 41)	0.76 (2.50)
log($SQ_{t+\Delta}/SQ_t$) (β)	0 34 (1.08)	0.28 (0.89)	0.88 (2.62)	0.62 (2.98)
R^2(Adjusted)	.1652	.1251	.0765	0964

*t statistics in parentheses.

model, but cannot be rejected for the daily model. For either case, however, the adjustment factors explain much less of the variation in the dependent variable than they do in the case of the traffic level models. Consequently the adjusted R^2 values are much lower for these models

Despite the limited explanatory power of the traffic growth models, the estimated coefficient on the available capacity term consistently has the expected positive sign, and is statistically significant (t statistic > 2). This coefficient can be interpreted as the elasticity of traffic growth rate to available capacity. Thus, using the daily traffic model without segment adjustment factors as an example, a 1 per cent increase in available capacity in year t results in a 0.8 per cent increase in traffic growth (e.g. from 10 per cent to 10.8 per cent) between year t and year $t+\Delta$.

The available capacity elasticity is substantially higher in the daily traffic models. This does not, however, imply that an increase in capacity will accelerate daily traffic growth more than peak period growth. If there is significant peaking, than the proportional increase in available capacity in the peak period from a given increase in total capacity will be significantly greater. For example, if peak hour traffic were 80 per cent of capacity and daily traffic 20 per cent of capacity, then a doubling of capacity would (prior to any demand response) increase unused capacity in the peak 500 per cent, while increasing daily available capacity only 125 per cent.

3.5 Assessment of Predictive Performance

We have now discussed two types of models that can be used to estimate the traffic induced from expanding road capacity, or more specifically $\varepsilon_{qc}(t)$. Before using them for that purpose, we assess their performance, in both comparative and absolute terms, by comparing their predictions with observed data for the observations taken after the completion of expansion projects. We focus on post-completion observations because it is for these years that we will need to predict traffic for the counterfactual scenario in which the capacity expansions did not occur

In this and subsequent sections, we confine our attention to the daily traffic models, for two reasons. First, daily traffic is more directly relevant to the objectives of this research. Second, we have more confidence in the daily traffic data.

The level model predicts daily traffic volumes directly. To use the growth model to predict such volumes, the traffic level one year after project completion is used as the basis for predicting traffic four years after completion. This prediction is then used as the basis for predicting traffic seven years after completion, and so on. Thus, traffic volume predictions from the growth model are available beginning in the fourth year after project completion.

We assess the performance of the models, first, by comparing predicted and observed traffic levels for selected individual segments, and second, by calculating standard errors and biases of the model predictions for the set of segments as a whole. Figures 3-4 to 3-9 show the individual comparisons for six sections, chosen quasi-randomly as those whose arbitrarily assigned section numbers are multiples of three These plots reveal that model performance varies widely. Segments 6, 12, and 18 have quite good fits, with the level models outperforming the growth model in the latter of these. Segments 3 and 9 show somewhat wider disparities between predictions and observations, with significant overprediction in the case of Segment 3 and underprediction for Segment 6. In both instances, the disparity is wider in the later years. Finally, the models are widely inaccurate for the later years in the case of Segment 15, the traffic counts for which are puzzlingly erratic.

Table 3-4 summarizes the aggregate performance of each model, by year since expansion completion. Two measures are presented. The standard error is the route mean square of the prediction error divided by the mean prediction value. The bias is the mean signed prediction error, also divided by the mean prediction value. Thus, for observations four years after project completion, the growth model has a standard error of 16 per cent, and a bias of +2 per cent.

The standard errors of the models are in the 10-15 per cent range for the first decade after project completion, increasing to 20-30 per cent in the second decade. These substantial errors demonstrate that none of the models can predict traffic on individual road segments following a capacity expansion very accurately. Biases, on the other hand, are much lower, implying that the models accurately predict total traffic across the segments on a year-by-year basis For all models, predictions for total traffic are within 5 per cent of observed values for years 4 and 7 after the improvement, and within 4 per cent for years 13 and 16 after the improvement. The models perform least well for years 10 and 19, with errors as high as 6 per cent in the former year and approaching 10 per cent -- based on just three observations -- in the latter. The models

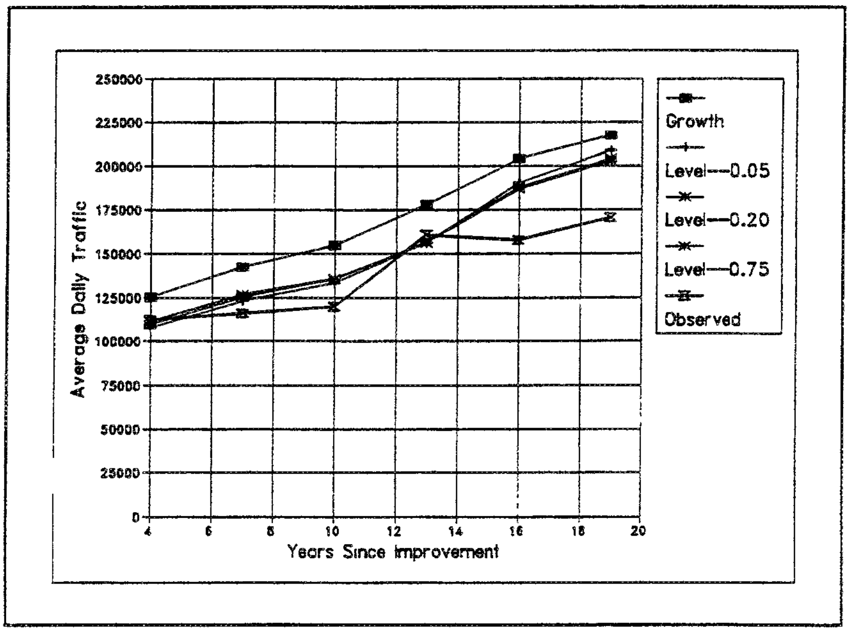

Figure 3-4
Model Predictions and Observed Traffic, Segment 3

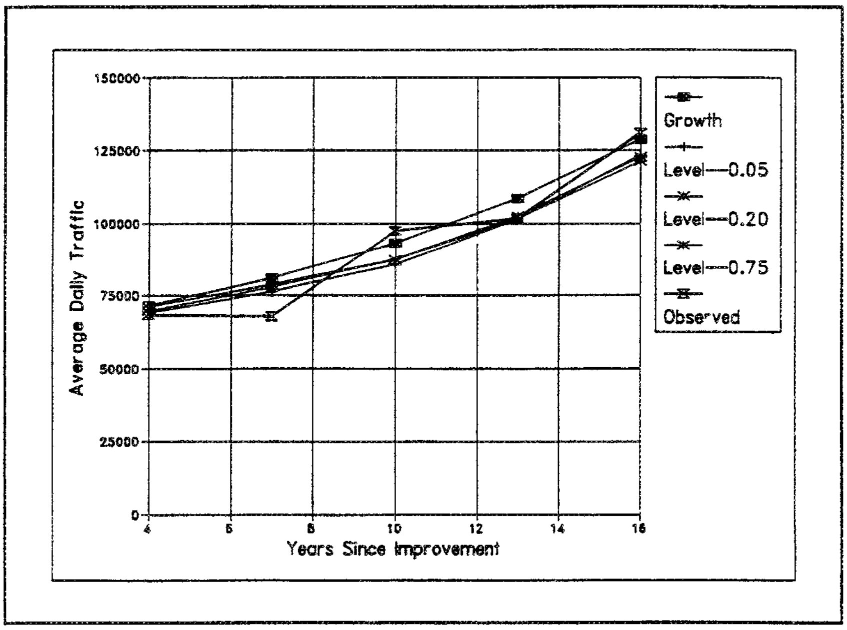

Figure 3-5.
Model Predictions and Observed Traffic, Segment 6

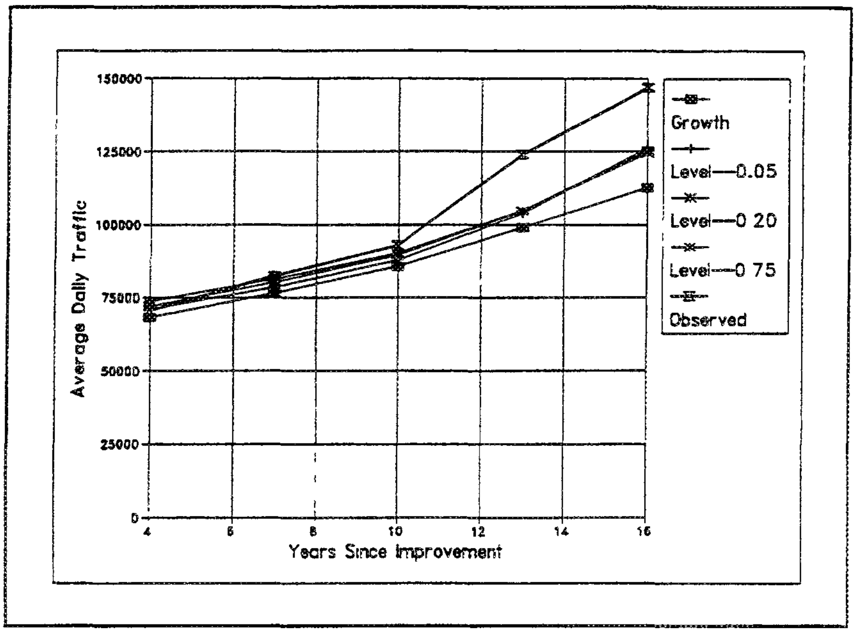

Figure 3-6
Model Predictions and Observed Traffic, Segment 9

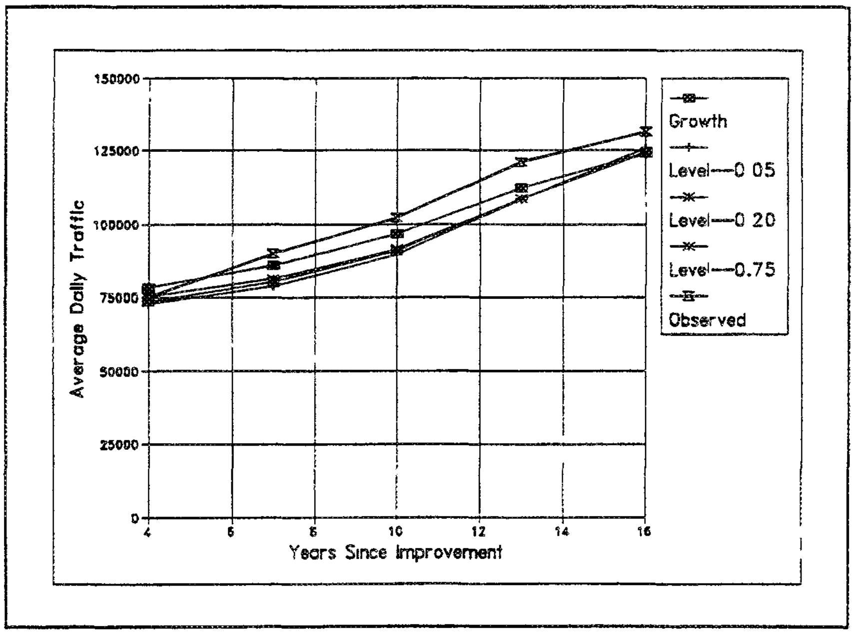

Figure 3-7
Model Predictions and Observed Traffic, Segment 12

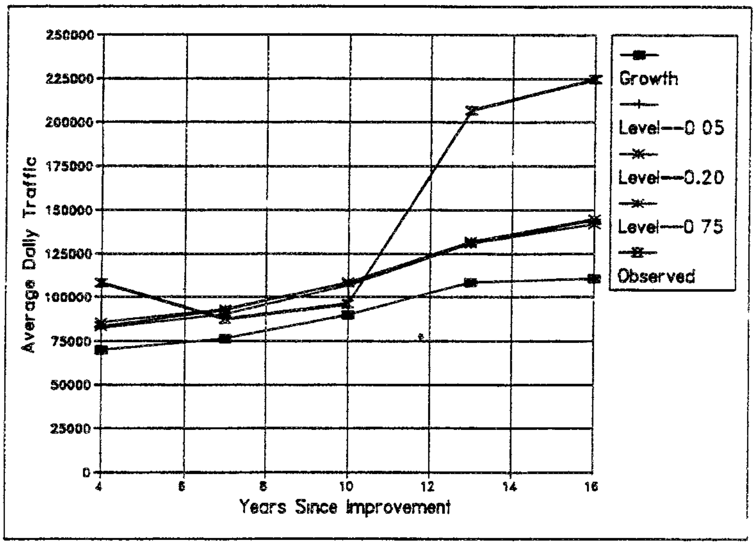

Figure 3-8
Model Predictions and Observed Traffic, Segment 15

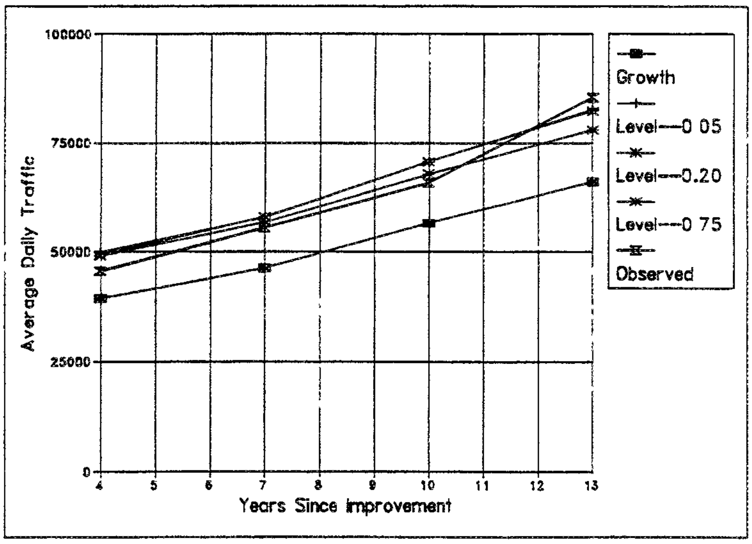

Figure 3-9.
Model Predictions and Observed Traffic, Segment 18

Table 3-4.
Predictive Performance of Daily Traffic Models

YEARS SINCE PROJECT COMPLETION(t)	NUMBER OF OBSERVATIONS	GROWTH MODEL		LEVEL MODEL σ=0.05		LEVEL MODEL σ=0.20		LEVEL MODEL σ=0.75	
		STD ERROR	BIAS	STD ERROR	BIAS	STD ERROR	BIAS	STD ERROR	BIAS
4	18	0.162	0.022	0.113	0.008	0.112	0.019	0.117	0.039
7	18	0.161	0.036	0.076	0.017	0.080	0.006	0.086	0.043
10	18	0.143	0.061	0.164	0.049	0.161	0.060	0.166	0.062
13	18	0.246	-0.030	0.262	-0.024	0.252	-0.023	0.258	-0.027
16	14	0.309	-0.008	0.231	-0.015	0.226	-0.022	0.232	-0.032
19	3	0.295	-0.044	0.258	-0.063	0.252	-0.075	0.266	-0.092

exhibit a consistent tendency to slightly overpredict traffic for the first decade after expansion and underpredict it for the second decade. These results suggest that roughly 10 years after a capacity expansion, there is an increase in traffic that none of our models adequately explains Referring to the individual segment results shown in Figures 3-4 to 3-9, evidence of such an increase is seen for Segments 3 (Figure 3-4), 9 (Figure 3-6), 15 (Figure 3-8), and 18 (Figure 3-9) Further research is needed to verify and explain this phenomenon.

Comparing the performance of the different models, the level models have virtually identical standard errors for any given year. Standard errors of the growth model predictions are somewhat higher than the level models for years 4, 7, and 16, and roughly the same for the other years. With regard to bias values, the level models with σ=0.05 and 0.20 are consistently better than the others for years 4, 7, 10, and 13, while the growth model performs best for years 16 and 19.

3.6 Estimates of Induced Traffic from Capacity Expansion

We use each of the four models to estimate the induced traffic from the 18 capacity expansion projects. To do this, we use the models to estimate the daily traffic on each segment, both with and without the capacity expansion, for the time periods 4, 7, 10, 13, 16, and 19 years after the expansion occurred. By comparing estimated traffic under the expansion and no-expansion scenarios, we estimate the traffic inducement from expansion, for each of the years considered

There is a difficulty in making these calculations for the growth model. The problem is that this model applies only to periods when the capacity at the beginning of the period is the same as the capacity at the end of the period. Suppose the capacity of a roadway is increased at time t=0. We cannot use the growth model to predict the growth in traffic from t=-1 to t=1. In order to estimate induced traffic using the growth model, we must assume that traffic at t=1 would be the same with or without the capacity increase, and then simulate traffic growth thereafter with and without the added capacity. If in fact traffic at t=1 is higher as a result of the capacity expansion, then this calculation method will underestimate induced traffic during the first years after the expansion. The magnitude of the underestimate will, however, decline over time, since the higher baseline traffic value will increase the impact of the capacity expansion on traffic growth.

Although the calculations are made on a segment by segment basis, the results of the last section indicate that results for any specific segment are not very reliable. Since the models are fairly accurate in predicting aggregate traffic over all segments, the aggregate estimates of induced traffic are much more credible. The aggregate results reflect the average response of traffic level to capacity increase. taken over a representative sample of road widening projects.

We again use traffic-capacity elasticity, $\varepsilon_{qc}(t)$, as our measure of induced traffic. For each model and year, we calculate this value as

$$\epsilon_{QC}(t) = \frac{\log(\sum_{i=1}^{n} Q_{it}^{e} / \sum_{i=1}^{n} Q_{it}^{ne})}{\log(\sum_{i=1}^{n} C_{i}^{e} / \sum_{i=1}^{n} C_{i}^{ne})} \tag{3-6}$$

Where:

Q_{it}^{e} is the traffic on segment i in year t assuming the capacity expansion at t=0,
Q_{it}^{ne} is the traffic on segment i in year t assuming no capacity expansion;
C_{i}^{e} is the capacity on segment i after the capacity expansion;
C_{i}^{ne} is the capacity on segment i prior to the capacity expansion.

Table 3-5 gives the elasticity results for each model and specified year after project completion. For example, the first entry on the table indicates that, according to the growth model, a 1 per cent increase in capacity will, on average, result in a 0.08 per cent increase in daily traffic on the improved segment four years later

The growth model yields a year 4 elasticity estimate well below those obtained from the traffic level models. This disparity results from the problem described above -- namely, that this estimate neglects any induced traffic that materializes up to the first year after project completion. Setting the growth model estimate aside, the other three models suggest an elasticity for year 4 in the 0.15-0.3 range.

Table 3-5.
Traffic-Capacity Elasticities ($\varepsilon_{qc}(t)$), by Model and Year Since Project Completion

YEARS SINCE PROJECT COMPLETION(t)	GROWTH MODEL	LEVEL MODEL σ=0.05	LEVEL MODEL σ=0.20	LEVEL MODEL σ=0.75
4	0.08	0.15	0.27	0.34
7	0.17	0.18	0.34	0.38
10	0.28	0.20	0.37	0.40
13	0.40	0.21	0.40	0.41
16	0.55	0.22	0.42	0.41
19	0.68	0.23	0.43	0.42

The growth model elasticities rapidly "catch up" with those of the level models, surpassing them by year 16. This pattern of rapidly increasing elasticities reflects the fact that the growth model predicts induced traffic to be greatest in cases where the additional capacity has the greatest impact on the available capacity, 1-Q/C. The impact is greatest when, in the absence of the new capacity, the traffic on the roadway would have been reaching its limit This may be some years after the expansion, depending on the level of traffic at the time of its completion.

Between years 10 and 16, three of the four models yield compatible elasticity estimates. These are in the range 0.3-0.4 for year 10. In year 13, all three estimates converge to 0 4, while in year 16 the range becomes 0 4-0.6. The one "dissenting" model for these years is the traffic level model with σ=0.05, which yields an elasticity of about 0.2 throughout this period (and indeed for the entire period covered in the table). There are several justifications for discounting the results from this model. First, its σ value was chosen as the lower extreme of the range that yield models that adequately fit the data. Second, such a low σ value is implausible, since it implies an extremely protracted adjustment process.[4] Finally, the long run elasticity for this model is over 1 -- implausibly high since this implies that a capacity increase ultimately results in a higher volume-capacity ratio.

In sum, despite the substantial variation in elasticity estimates shown in Table 3-5, there are good reasons for discounting many of the outlying values. When this is done, a credible range of $\varepsilon_{qc}(t)$ can be identified for values of t up to 16 years. This range is 0.2-0.3 for t=4 years, 0.3-0.4 for t=10 years, and 0.4-0.6 for t=16 years. The models do not yield a consistent result for higher t values, reflecting the lack of empirical observations in this domain. Nor is there a consistent estimate of how $\varepsilon_{qc}(t)$ changes with time. The growth model portrays the elasticity growing markedly even 10 years after the capacity expansion is completed, while the level models suggest a much slower pace of adjustment after the first few years.

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[4] The length of the adjustment process can measured as the value of $t_{½}$, defined by the equation $\varepsilon_{qc}(t_{½})=\varepsilon_{qc}(\infty)/2$ For the model with σ=0 75, $t_{½}$ is about 2 years, while for the σ=0 2 model it is approximately 15 years For the model with σ=0 05 on the other hand, $t_{½}$ is about 50,000 years!

3.7 Conclusions

In this chapter, we have investigated how expanding the capacity of an urban highway affects the level of traffic on that highway. Using traffic count data from 18 segments that have undergone such expansions, all located within urban counties in California, we have sought general relationships characterizing this effect We recognize that the traffic inducing impact of a given project will depend on many particular features not considered here. These individual differences ought not, however, discourage the search for broad generalizations.

Our analysis has produced three conclusive results. The first is that capacity expansion does induce traffic on the expanded facility Second, this effect occurs over an extended period -- at least one decade and quite possibly two. Third, even after two decades, ε_{qc} is well below 1, implying that expanding the capacity of an urban highway normally leads to a long term reduction in its volume-capacity ratio. Thus, a capacity expansion is likely improve level of service on the expanded facility for an extended period, although perhaps not indefinitely.

Despite these points of convergence, we have found different models with contrasting implications fit the data used in our analysis. A traffic level model that implies a low long run elasticity and rapid adjustment fits the data roughly as well one with a high long run elasticity and slow adjustment. A growth model that portrays accelerating traffic gains some ten years after a capacity expansion performs nearly as well as traffic level models in which such gains have slowed markedly by that time. These uncertainties reflect variability in the data, which in turn derive from the fact that the traffic inducement impacts of adding capacity differ from segment to segment. In this respect, our results are consistent with the wide range of traffic inducement impacts found in previous research, discussed in Chapter 2.

More data and better models would allow a much richer portrayal of the traffic inducing effects of highway capacity expansion. Annual traffic counts, as opposed to the tri-annual figures available for this study, would allow time series models for individual segments to be developed. More general model specifications that are compatible with the assumptions of both the traffic level and traffic growth models would allow a more complete picture of how induced traffic grows following a capacity expansion. Together, these enhancements would enable us to accurately characterize the traffic inducing impacts of specific projects, and to relate these impacts to roadway and project attributes. Such results could enable us to make reliable, empirically grounded, estimates of how a specific expansion project will affect future traffic. This would greatly improve our ability to make realistic environmental and economic assessments.

Chapter 4:

Freeway Expansion and Land Development: An Empirical Analysis of Transportation Corridors

4.1 Introduction

Freeways as part of a region's transportation infrastructure can, together with other factors, influence location choices and development decisions involving residential, commercial, and industrial development. The network of roads and highways provides a means for access for workers and materials as well as a way for distributing products and services. Greater access not only lowers the costs of transportation and transactions but also increases the supply of many resources. For example, more land of a given type is available, a larger labor force from which employers may select is accessible, and a broader set of suppliers is at hand. Therefore, an investment in highway infrastructure can have a variety of land use outcomes depending upon which of the above factors have been affected and whether they are important. The impact will also vary with the nature of the investment. For example, if a new freeway is built where none existed previously, we might expect both the type and magnitude of impact to differ from cases in which capacity of an existing facility is expanded. The impacts of enhancements to radial and circumferential routes may also differ.

There is a sizable literature concerning transportation investment impacts on land use, land values, development activity, social and community variables, and local and regional economies. The studies have been carried out in a number of different communities in the U.S. and have used several different evaluation methodologies. There, however, is a paucity of work with a solid analytical basis or that employs statistical models that can distinguish among the various effects on the variables of interest. Much of the literature uses a case study format that is highly descriptive and yields anecdotal information. In the end such studies are often inconclusive concerning the existence of linkages, and invariably so with regard to their magnitude. Also, the literature has failed to distinguish between the building of a new road where none had existed previously and expanding the capacity of an existing facility.

To fully assess the impact of a highway improvement it is necessary to address the following four questions: (1) what effects did the investment have on population, employment, trade, travel and environmental variables, and residential mobility? (2) why did the effects occur, in other words, what was the mechanism through which the investment affected the other variables? (3) who was affected? and (4) how could the effects be managed in order to obtain the maximum benefits possible or ensure the desired objectives are realized?

In the absence of the capacity enhancement location decisions and the rate of development across a region will be determined by market conditions combined with the land use planning and process environment Development and changes in land use will respond to a combination of forces including population trends, income growth, interest rates, zoning approvals, and planning decisions. Consequently, there will be some flow of land from one type of use to another. If a transportation enhancement is undertaken, such as adding capacity to an existing freeway, this flow may change If, for example, the added capacity makes a particular parcel of land more accessible or reduces congestion and thereby decreases travel time, the value of the property along with the type and intensity of land use may respond. The consequence of the investment may be additional net development or alteration of its timing. This is illustrated in Figure 4-1 in which some *rate of land development* (including the net addition to total developed land and the net increase in development intensity) is indicated by three alternative lines marked path 1, path 2, and path 3. The figure illustrates land development occurring at some pace over time. Suppose a capacity enhancement takes place at some point in time. The addition to infrastructure may affect land development and may do so in different ways.[1] Path 1 represents a case in which land development is temporarily accelerated, but without a net long-run impact in the amount of development. In paths 2 and 3 there is both an acceleration and a net increase in development; in the former the acceleration is gradual and temporary, and the net increase is slight, while in the latter the impact is more sudden, stronger, and longer lasting. The paths are likely to be different for different land uses.

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[1] Land use may not be affected in which case the path would be horizontal

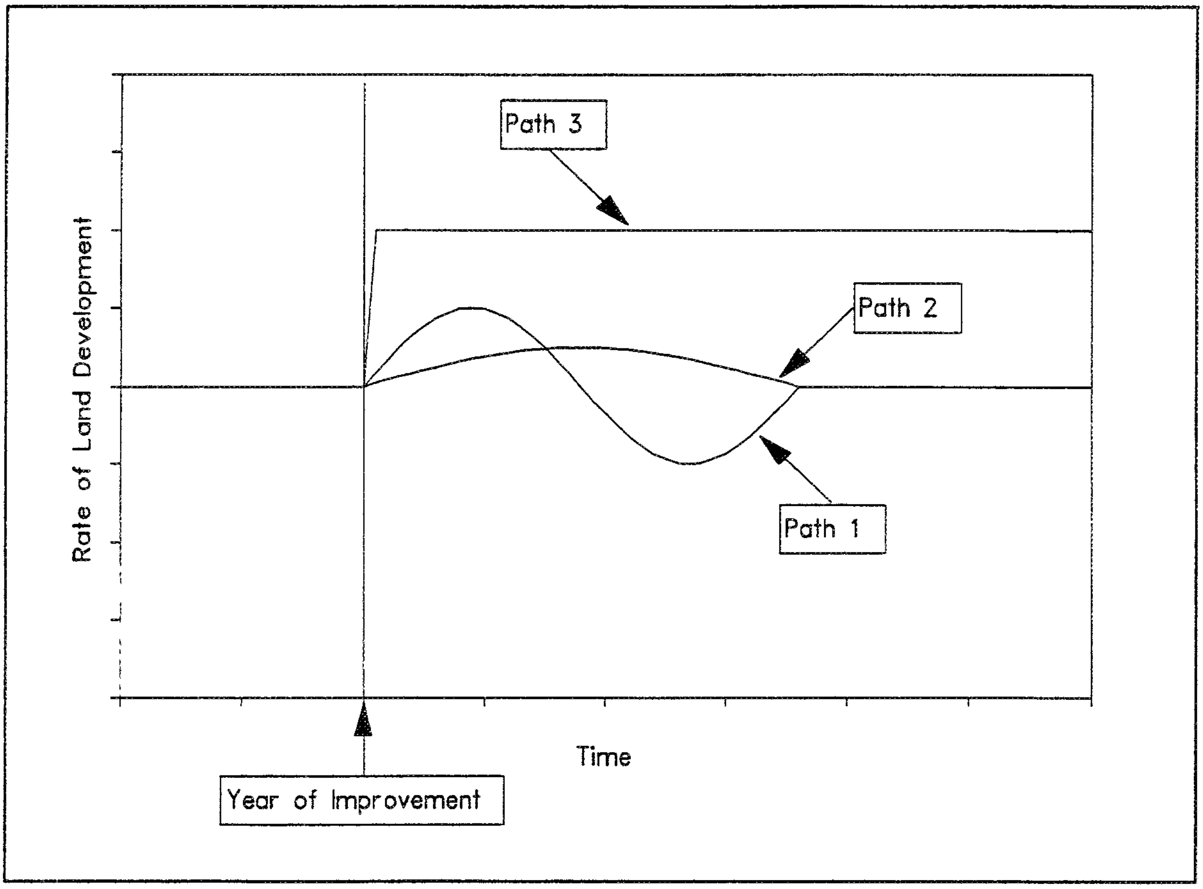

Figure 4-1.
Possible Impacts of Highway Expansion on Land Development

There is a consensus in the literature that while growth and development will be limited without adequate transportation capacity, transportation investment in and of itself is not a sufficient condition for growth and development; see, for example, Payne-Maxie (1980). A key finding consistent across much of the literature is that capacity investments will have some site-specific effects but that primarily they serve to redistribute economic activity either (or both) temporally, shifting development forward in time, or spatially, shifting the location of development from one point to another. It is also widely held that additional capacity will marginally increase the growth rate of growing areas, but is generally not sufficient to change an undesirable investment area into a desirable one

Land use is governed by the demand for land, the available supply, and the restrictions, such as zoning, placed on use by government. The use of land for housing will be affected by the trade-off between people's desire for more land for housing and their distaste for commuting. According to the standard (and admittedly oversimplified) theory, household will locate where the reduction in housing costs are just offset by the additional cost for commuting to opportunities.[2] As access becomes more difficult, people will try to lower their access costs by moving closer to their primary destination -- generally their work location. People, for example, may start out in an urban area living in the suburbs because they have a high preference for more land and housing and access to work is relatively high. As traffic and congestion builds, access costs rise and households may seek to move closer to work and be willing to pay more for housing in order to reduce access costs. This will increase the demand for more dense housing or multi-family housing and decrease, relatively, the demand for single family homes. Land use will change when the rate of return in alternative use is adequate to justify a transfer. For example, land closer to employment centers, in an established urban area, may shift from single family homes to multi-family dwellings if there is an excess demand for land with lower commuting costs and/or if the land is made more accessible via an investment in transit or automobile infrastructure

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[2] Opportunities include work, shopping, recreation, and visiting friends and relatives

As rent or the return to land changes the use to which particular parcels of land are put also changes. Land holders at the fringe will adjust the amount of land which is being held in inventory for future development This means that in the absence of any investment in road capacity there would be some rate of inventory adjustment. A transportation investment may alter this rate. Similarly, the rent to land is determined in land markets by demand and supply The demand for land will be determined by its ability to be productive or to generate utility. If land rent is "too high" relative to current use, it must be made more productive or made to yield more utility. Both of these may be accomplished by increasing the density of land use Thus, for example, we may see more of a tipping of land from single family residential to multi-family dwellings as a result of a transportation capacity improvement.

As an example, consider the consequences of adding a lane to an existing facility in a given urban corridor where population growth or in-migration are held constant for the moment. With the expanded lane capacity housing beyond the location of the investment becomes relatively more valuable since the cost of the commute has increased. Since it is more valuable, households will increase their bids. Rents will rise and the boundary of the urban area will expand Rents close to the employment center will fall since these locations will become less valuable relative to other locations in the region, so households will be willing to bid less for them If we now take account of the fact that these types of investment are taking place in a dynamic urban environment, the conclusions are not substantively altered. The increase in demand for land and housing closer to the city center will be relatively less with the transportation investment than without it. Land values near the center may still rise but part of the increase may now be diverted to those parcels which are made relatively more attractive because of their greater accessibility resulting from the capacity expansion.

Griggs (1983) and Palmquist (1981) both found that capacity investments such as new interchanges and roadway expansion affect property value appreciation Netting out the externality of increased noise, property value appreciation was approximately 15 per cent. Such appreciation means that developers will desire to use less land and more capital to create a given amount of building space. Thus, the effect is to shift the land use from low to high density. Additions to road capacity may catalyze such changes. They will not, however, cause land for which there was no demand prior to the expansion to suddenly become valuable. The evidence is that income generating properties such as retail space, office buildings, and multiple family dwellings may be affected by capacity investments or additions (Payne-Maxie, 1980). However, the level of development will depend, for the most part, upon a combination of economic, financial and land supply variables. Transportation investments enhance this process, but they do not create it.

In this study we investigate land use impacts of highway capacity expansion projects in several corridors, all located in California's four largest urban areas. Our interest is in determining whether, controlling for other factors, the expansion had a significant effect upon land use in the corridors served by the expanded roadway Section 4.2 provides a description of the analytical framework used in the research. Section 4.3 contains a description of the variables used in the statistical analysis and the areas from which the data were collected. Summary statistics are used to provide a picture of the overall growth trends in each area. Section 4.4 presents an exploratory analysis of development impacts from road capacity expansion, based on simple graphical techniques, and argues that this indicates the need for more rigorous statistical analysis. Section 4.5 documents the procedure for this analysis, and Section 4.6 discusses its results. A summary and conclusion are contained in Section 4.7.

4.2 Analytical Framework

Our approach in this research is to develop an analytical framework through which the impact of capacity enhancement projects can be statistically evaluated using empirical data. To meet this objective, it is important to have sufficient variation in the data. This is accomplished by creating a "panel" of corridors in which highway capacity expansions have occurred. The "panel" includes a number of corridors with a large number of years of information for each This enables us to detect significant, generalizable, land use changes arising from completion of a capacity enhancement project. Furthermore, by having a number of different projects included in the data, we avoided drawing conclusions based on one or two projects that might involve unique circumstances. The projects we selected reflected the broad set of circumstances that exist in California, as opposed to one geographic or urban area

Different types of land use changes, including residential, commercial, and industrial development, are considered. Much of the previous literature has focussed upon one type of land use when examining the outcome of a new highway facility or a capacity enhancement project. We want to ascertain whether one type of land use is affected more than, or in a different way from, another

In order to empirically investigate the land use consequences of a capacity enhancement project, a broad set of data is needed. First, an accurate representation of the land development activity before and after the project is necessary. Second, we require demographic, socio-economic, and financial variables that can affect land use, so we can be confident that any measured impact of a capacity expansion is not in fact capturing the influence of other, excluded, variables.

Development activity in an urban region is subject to both local and regional influences. For example, growth in single family homes in Contra Costa county may result from housing demand associated with economic activity in downtown San Francisco, rather than a recently completed capacity enhancement project in a corridor in Contra Costa Therefore, the information contained in corridor data is partly reflecting what is occurring at the broader regional level and partly due to what is happening in the corridor. It is thus important to distinguish and control for these broader regional influences by normalizing the variables used in the empirical examination This is explained in greater detail below.

4.3 Data Description: Variables and Geographic Study Areas

Our analysis is based on a set of corridors located in the four largest urban areas in California. There were many capacity enhancement projects in these regions in the past two decades. Projects are selected from an annual publication from Caltrans entitled State Highway Program, Financial Statements and Statistical Reports which provided the size, cost, and date of completion of projects. The single most important criterion in selecting a project for inclusion in the data set is that it be a capacity enhancement of a controlled access radial artery, completed between 1970 and 1985.[3] These years are selected so that information covering a sufficient period on either side of the project completion date is available. Once the projects are chosen,

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[3] One project in the Los Angeles area had a second phase completed in 1988

the communities most directly impacted by them are identified. Any community located in the affected corridor, and whose route to the central city of the region would normally include the expanded road section, is chosen.

All corridors are located in one four major metropolitan regions of California: the San Francisco Bay Area (9 counties); Sacramento (6 counties), Los Angeles-Long Beach (3 counties), and San Diego (1 county). Over the past three decades all of these areas have experienced high rates of growth. They have also had a significant amount of investment in highway infrastructure in the past twenty to thirty years. Three of the corridors are in the Bay Area, one in Sacramento, and two each in Los Angeles and San Diego. The corridors are identified and described in Table 4-1 Note that in four of the eight cases more than one capacity expansion occurred over the study period. This complicated the analysis, since for years after the second expansion the impacts of both expansions must be considered. Our procedure for doing this is discussed below.

A preliminary examination of data for the four regions provides some insight into the differences in their sizes and growth trends. These data are plotted in Figures 4-2 and 4-3, where population growth and income growth, respectively, are illustrated. The San Francisco, Sacramento and San Diego areas all have similar trends in population growth. All three experienced a steady increase in population in the early 1980s that has since slowed. Los Angeles, on the other hand, expanded throughout the 1970s and 1980s, with a remarkable surge in population after 1980. Trends in income growth are more varied. Los Angeles is again the leader in both size and variability. Income growth has trended upward with slight dips in 1971, 1975 and 1982, all years of national recession Los Angeles has a dramatic income increase after 1982, with a growth rate far exceeding any previous period or any of the other regions. San Francisco seems to have a steadier income growth than Los Angeles with only slight decreases from the trend in the recession years, with the exception of 1982 In further contrast, San Francisco's income growth after 1982 is only marginally stonger than the previous trend. San Diego and Sacramento both have relatively smooth income trends over time; the significant presence of government expenditure in their economic base may explain this. San Diego seems to have suffered a significant downturn in 1987 but has recovered in subsequent years.

As noted above, the data set consists of eight corridors in the four regions. It is intended to support a reasonable empirical test of the null hypothesis that "highway capacity enhancements

Table 4-1.
Study Corridors

No	Route	Improved Segment	Region	Cities Affected	Year Completed
1	I-580	Dublin to San Leandro	San Francisco	Castro-Valley, Dublin, Livermore, Pleasanton & San-Leandro	1978 & 1988
2	I-680	Walnut Creek to San-Ramon	San Francisco	Walnut Creek	1974
3	SH-101	GG Bridge to Richardson Bridge	San Francisco	Mill Valley, Larkspur & Corte Madera	1975
4	I-80	Auburn to Roseville	Sacramento	Auburn, Loomis, Rocklin & Roseville	1977
5	SH-101	Oxnard to Thousand Oaks	Los Angeles	Camarillo, Oxnard, Port Hueneme, Thousand Oaks & Ventura	1975 & 1988
6	I-5	San-Juan-Capistrano to San-Clemente	Los Angeles	San-Juan-Capistrano & San-Clemente	1973 & 1982
7	I-15	San-Marcos to Miramar	San Diego	Escondido, Poway & San-Marcos	1977 & 1982
8	I-5	Chula-Vista to Imperial-Beach	San Diego	Chula-Vista, National-City & Imperial-City	1973

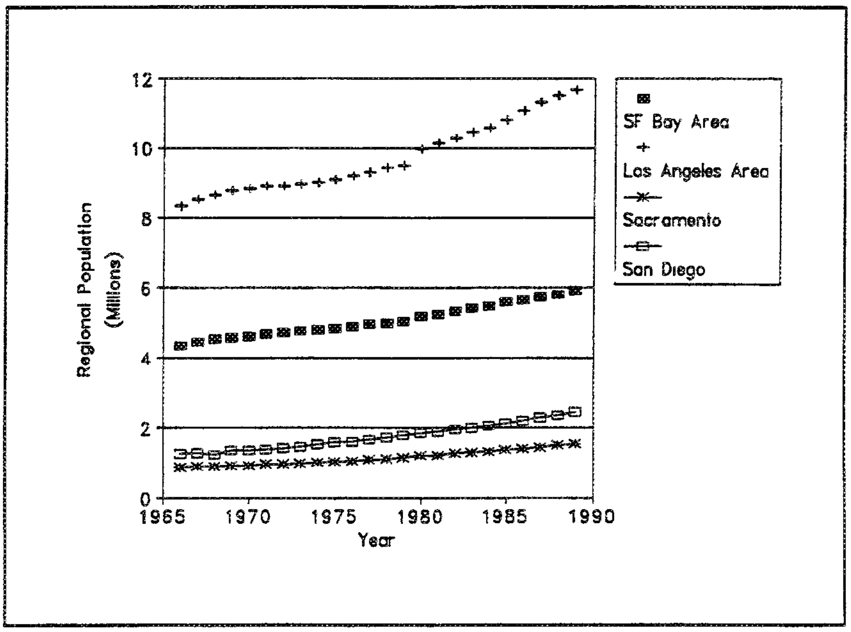

Figure 4-2.
Population Growth, California Urban Regions

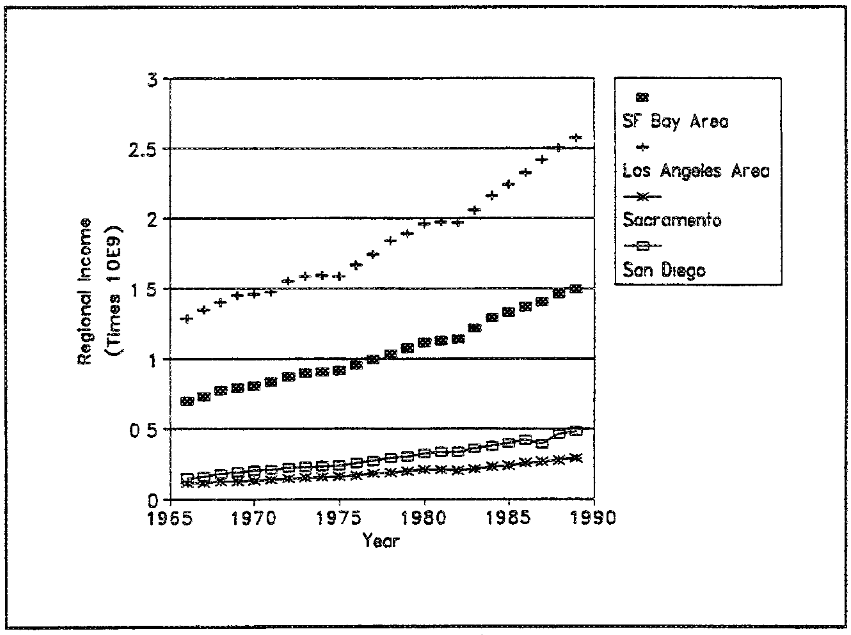

Figure 4-3
Income Growth, California Urban Regions

have no effect on land use." First, the number of projects exceeds the number of regions in order to insure that the results are robust and not unique to a particular project, corridor, or region. Second, to distinguish the impact of the capacity enhancement from the effect of factors influencing the region as a whole, dependent and independent variables for the study corridors are normalized by their values for the region. For example, the income in the corridor is normalized by dividing it by the income level for the region. All dependent variables are also normalized in this way.

Several dependent variables are used as to explore the impact of capacity enhancements on land use. All are based on building permit activity, data for which are available at the city level from the U.S. Census. Residential permit activity is measured in terms of the number of housing units for which permits were granted. Commercial and industrial permit activity is quantified based on cost of permitted construction. Note that these variables are all flow variables that measure the rate of development. For example, one dependent variable employed in the analysis is the growth in single family homes as measured by the number of such units for which building permits issued in a given year. This variable measures the addition to the existing stock of single family homes each year rather than the total number of such homes.

Thus, after normalizing for regional trends, the four dependent variables are:

1. annual permits issued for single family units in the corridor/
   annual permits issued for single family units in the region;

2. annual permits issued for multi-family units in the corridor/
   annual permits issued for multi-family units in the region;

3. annual total cost of permitted commercial construction in the corridor/
   annual total cost of permitted commercial construction in the region;

4. annual total cost of permitted industrial construction in the corridor/
   annual total cost of permitted industrial construction in the region.

The set of independent variables form several groups and encompass information on socio-economic variables such as income and population, transportation information such as transit expenditures and the status of the expansion projects (whether they are complete, and, if so, for how long), and planning variables such as the "available population capacity" of the region. The socio-economic variables included as independent variables were population (obtained from the California Statistical Abstract), total personal income (from the U.S. Census Current Population Reports), gasoline price index (from the California Statistical Abstract), construction cost index (from the Engineering News Record), and the "available population capacity" as measured by the difference in the population predicted by planners (obtained from the various regional planning agencies) for the region for the year 2001 and the current population.[4] Where appropriate the corridor variables are normalized by regional variables.

The group of transportation variables include transit expenditure information and completion dates for the capacity enhancement project. The transit expenditure variable, defined as the sum of local transportation fund (TDA), federal, state, and local capital grants and non-governmental donations, controls for the impact of these expenditures on land use changes, but is found to be statistically insignificant. Also included within the transportation group of variables are the key set of independent variables designed to measure the land use impact of the expansion These include dummy variables used to identify when a project was completed: that is, a variable is set to 1 for the year after a project was completed and for each subsequent year, while for all other years it has the value 0. We also include a time variable equal to 0 in the year the project was complete and incremented by 1 in each subsequent year. Thus, a project completed in 1985 would have a value for this variable of 0 in 1985, 1 in 1986, 2 in 1987, 3 in 1988, 4 in 1989 and 5 in 1990. When warranted, the square of the time variable is also included. Together, the expansion completion dummy and the time variable(s) define a first or second order polynomial in time since project completion designed to capture the dynamics of the land development response to a road capacity increase.

Because of gaps in the data and changes in the composition of some of the urban corridors area over the period of analysis, the dummy variables DC1 and DC2 are included in the model. These variables indicate cases in which a new city was incorporated in a corridor sometime during the analysis period. Corrections are necessary in these cases because permit data for unincorporated areas are available only at the county level, so that permits in unincorporated areas affected by the capacity expansion cannot be counted.

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[4] Population density would have been a better measure for our purposes but not all cities in the sample had projections regarding their size

Two additional dummy variables, FREEZE and CAP, are used only for the I-580 corridor (Corridor 1 in Table 4-1) The City of Pleasanton placed a freeze on land development in 1972, because of inadequate sewage treatment capacity. This event is reflected in the FREEZE variable. In 1976 Pleasanton received federal financial assistance for new sewage treatment facilities, and the city terminated the freeze but placed a 2 per cent limit on growth of residential projects that is still in effect. The years during which the limit was in effect are indicated by the variable CAP.

4.4 Graphical Analysis of Capacity Expansion Land Use Impacts

Before undertaking any regressions, we examine the data for each of the dependent variables, disaggregating the information by corridor and region Simply observing the cumulative and annual values for the land use variables over time and correlating them to the year of completion of a capacity enhancement project provides a first pass at determining if there are any impacts. Results for two of the eight corridors contained in the panel are presented below to illustrate the approach.

Figures 4-4 and 4-5 illustrate cumulative single family housing permit activity for the two example corridors Figure 4-4 is based on an expansion of I-580 in eastern Alameda county (part of the San Francisco Bay Area) while Figure 4-5 is the same variable but for I-5 in the San Diego area. To provide a picture of what is happening over time to the total or cumulative value of single family home permits, the value for each year is added to the previous year, using 1966 as the base year. The difference in the values between 1966 and 1989 represents the total number of permits for single family homes issued between these years. There are clear differences between the I-580 and I-5 areas. For I-580 the growth of single family homes in the corridor differs markedly from that in the region and there is a discernible acceleration in single family housing construction after the completion of the capacity enhancement project. However, this acceleration also coincides roughly with the lifting of the development freeze in this corridor in 1976. Thus the graph sheds little light on the individual contributions of these two events. For I-5, the behavior in the corridor parallels that of the region with no apparent impact from completion of the capacity enhancement project. These differences are made clearer if the annual values for the single family home variables are graphed, as in Figures 4-6 and 4-7. It is evident

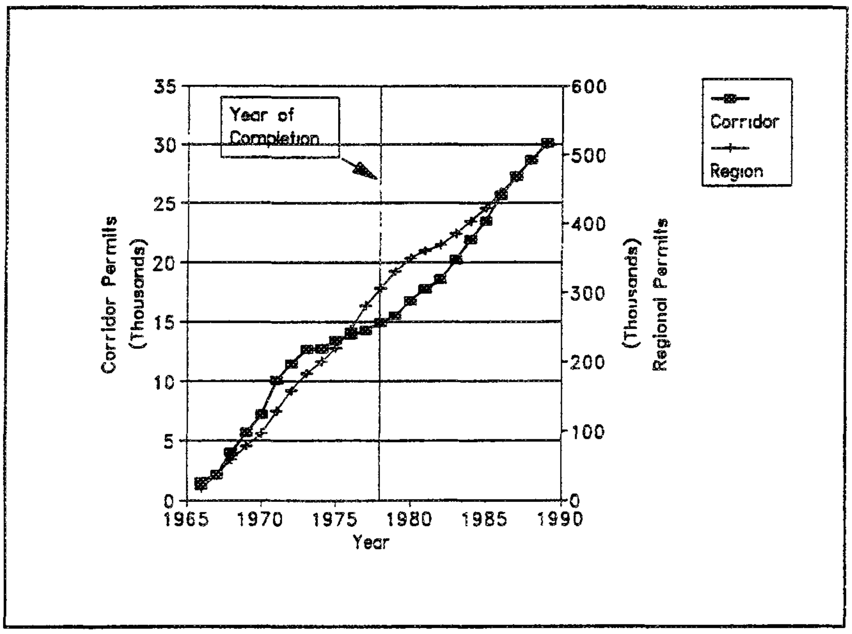

Figure 4-4. Cumulative Permits
Single Family Housing Units, I-580 Corridor

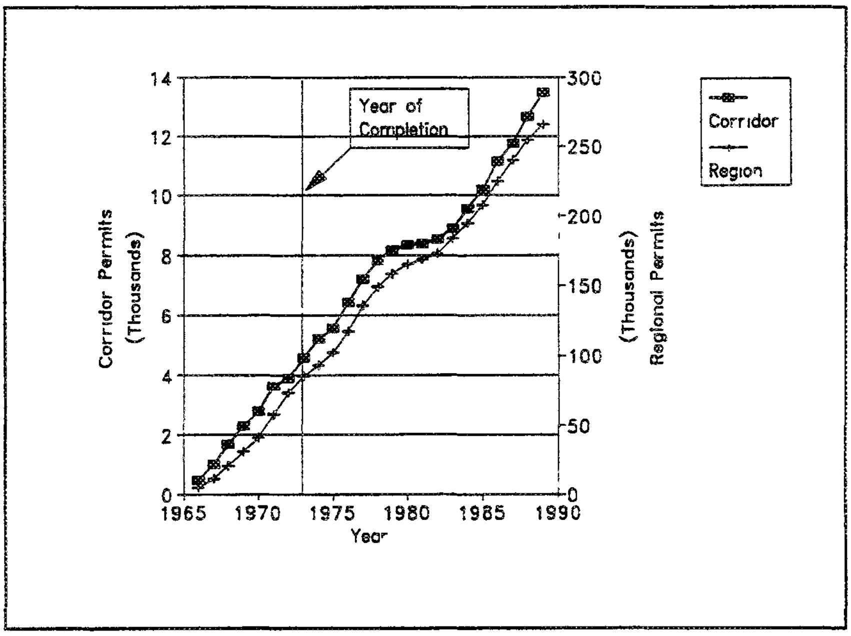

Figure 4-5 Cumulative Permits
Single Family Housing Units, I-5 Corridor

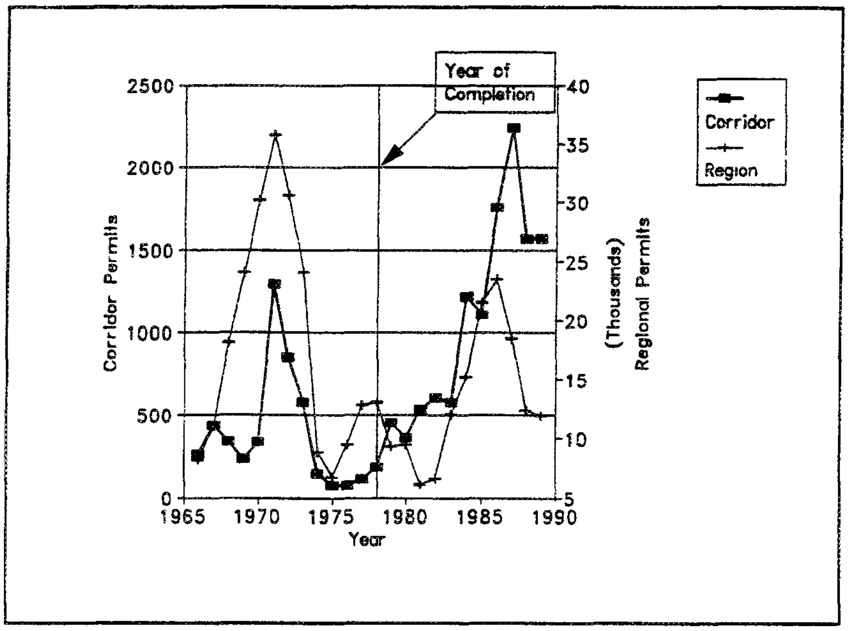

Figure 4-6. Annual Permits
Single Family Housing Units, I-580 Corridor

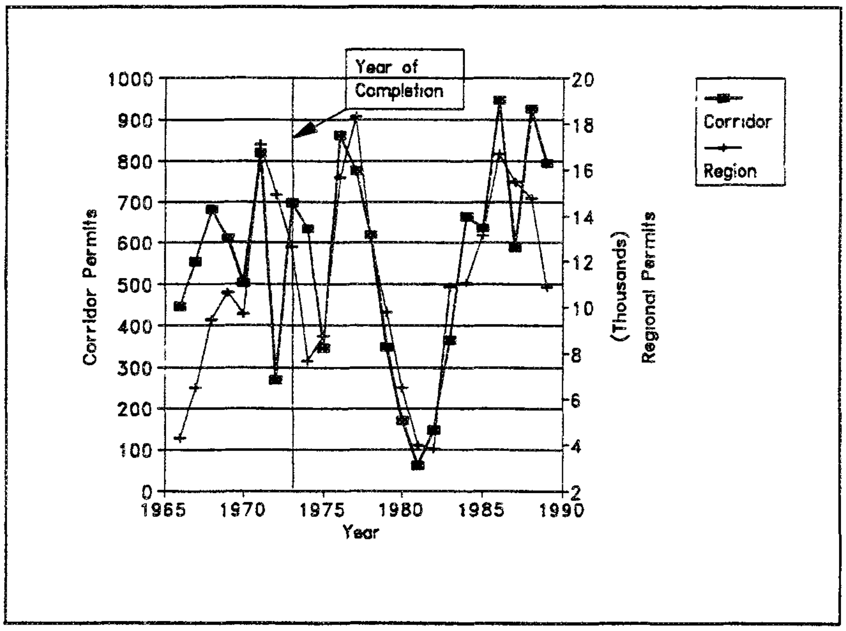

Figure 4-7. Annual Permits
Single Family Housing Units, I-5 Corridor

in Figure 4-6 that the I-580 corridor behaves quite differently than the region and that after completion of the capacity enhancement project, there is an increase in single family home permit approvals relative to the region. The evidence is different for I-5 with the annual changes for the corridor and region moving together and no clear change after the capacity project is completed.

In Figures 4-8 and 4-10, the cumulative and annual numbers of approved permits for family homes are exhibited for the I-580 corridor. From Figure 4-8, the behavior of the region and corridor again appear quite different, with a significant relative increase in the cumulative corridor permits after the capacity addition. This is also evident in Figure 4-10 in which annual permits for multi-family homes are plotted As with single family homes there is an upward trend after the year of completion and the increases for the corridor are larger than for the region, but also as before the lifting of the development freeze precludes a definitive interpretation. The comparable figures for the I-5 area are contained in Figures 4-9 and 4-11. As in the case for single family home approvals there is little indication that the I-5 expansion stimulated family housing development. Indeed, it appears that permit activity in the corridor decreased relative to the region after the expansion.

Figures 4-12 and 4-13 illustrate the cumulative construction cost (in constant $) of non-residential building permits -- both commercial and industrial -- for the I-580 and I-5 corridors, respectively. Annual permit levels are plotted in Figures 4-14 and 4-15. In this case, there is evidence of the expansion affecting permit activity on both corridors. However, the timing of the impacts appears to differ. In the case of I-580, there is a prolonged acceleration in development, extending at least through the first dozen years after expansion. Non-residential development in the I-5 corridor increases dramatically during the first four years after the expansion. While the pace continues to be high in years thereafter, this seems to result from a regional trend rather than circumstances unique to the corridor.

Scanning these figures it becomes evident that they do not support definitive conclusions as to whether a capacity enhancement project has an impact on land development. From the evidence contained in these figures it sometimes does and sometimes does not. Furthermore, even when there appears to be a positive correlation between capacity enhancement and permit activity, the net contribution of this event relative to other factors cannot be readily discerned.

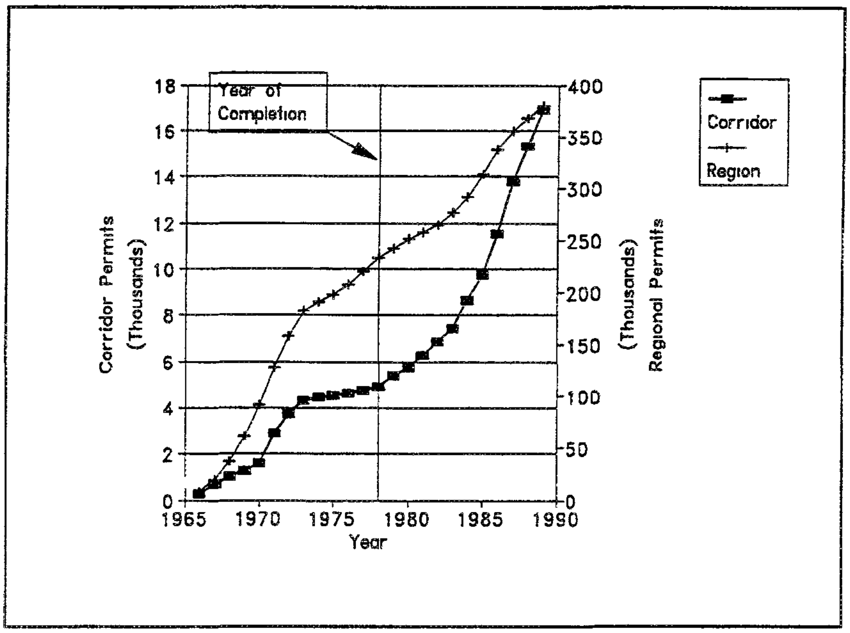

Figure 4-8 Cumulative Permits
Multi-family Housing Units, I-580 Corridor

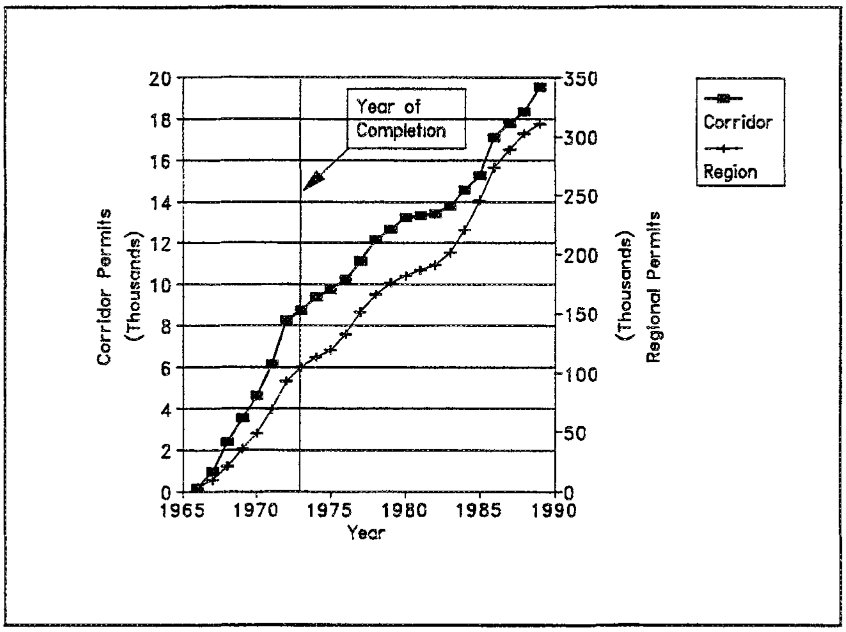

Figure 4-9. Cumulative Permits
Multi-family Housing Units, I-5 Corridor

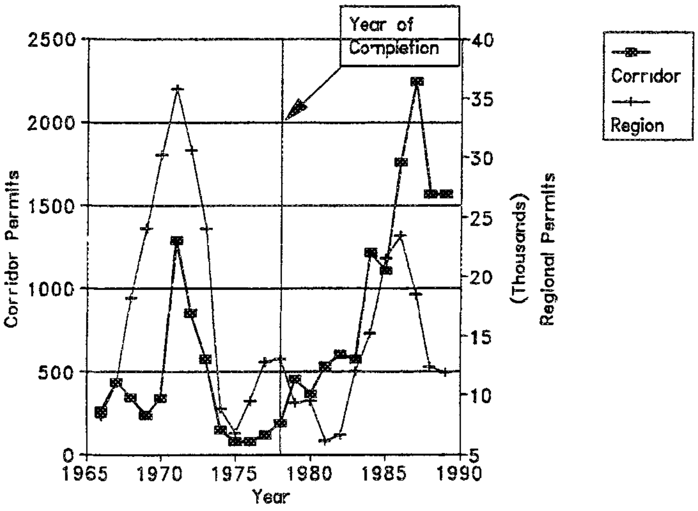

Figure 4-10. Annual Permits
Multi-family Housing Units, I-580 Corridor

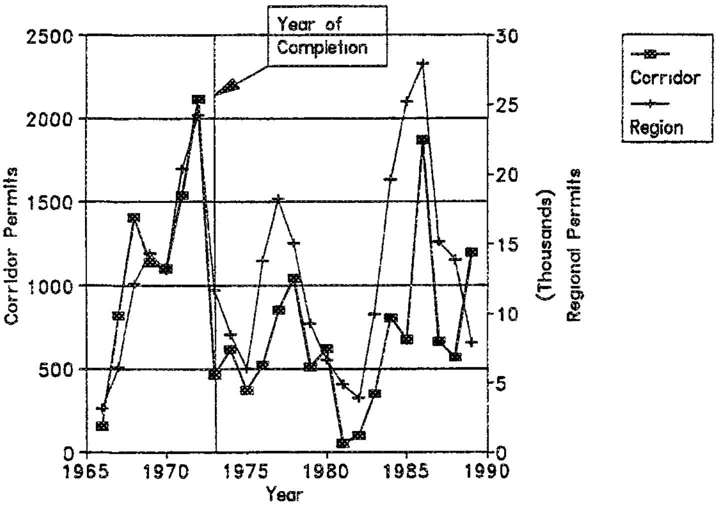

Figure 4-11. Annual Permits
Multi-family Housing Units, I-5 Corridor

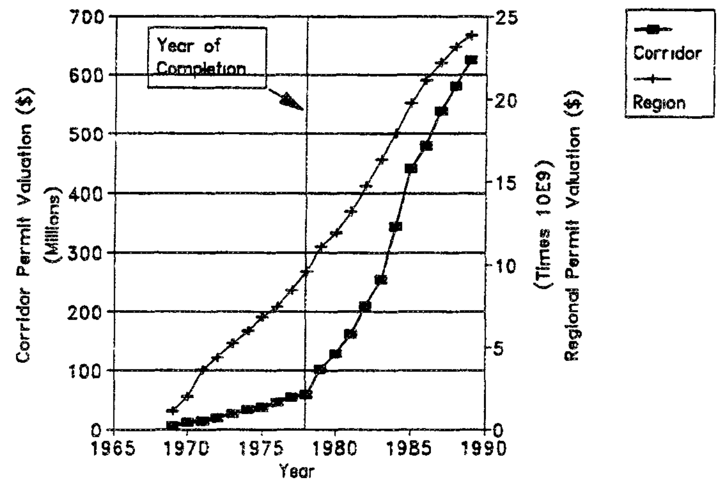

Figure 4-12. Cumulative Permit Valuation
Commercial Construction, I-580 Corridor

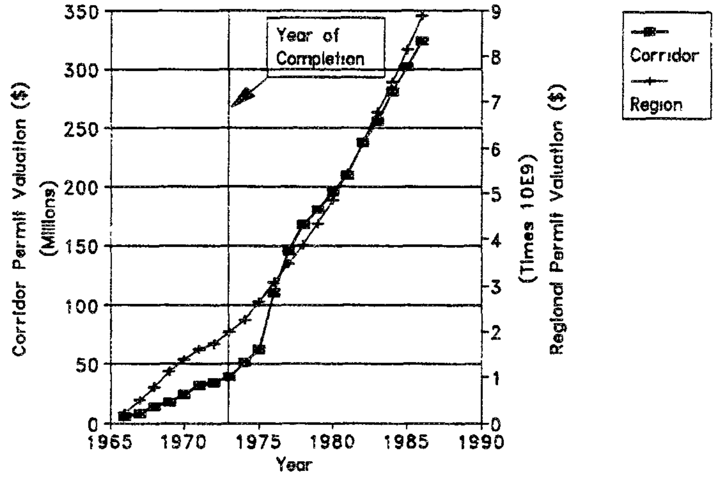

Figure 4-13. Cumulative Valuation
Commercial Construction, I-5 Corridor

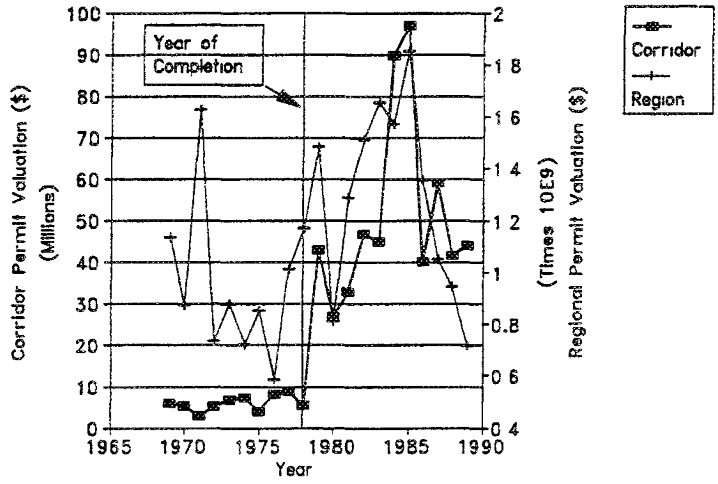

Figure 4-14. Annual Permit Valuation Commercial Construction, I-580 Corridor

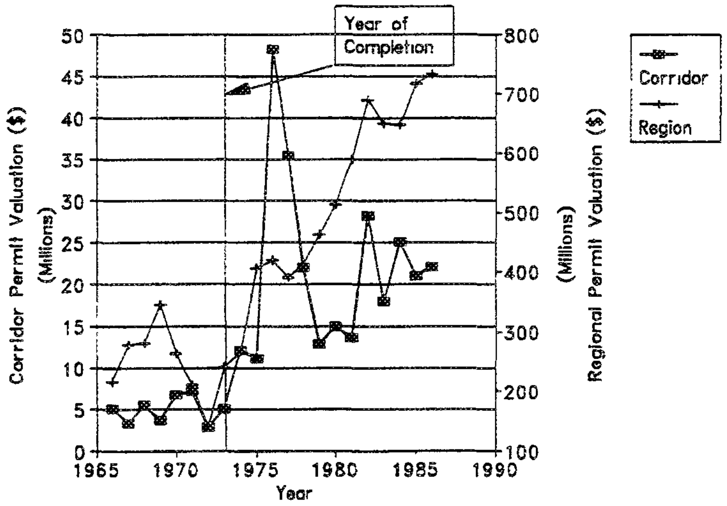

Figure 4-15. Annual Permit Valuation Commercial Construction, I-5 Corridor

For example, development constraints resulting from lack of sewage capacity may have influenced activity on the I-580 corridor as much or more than the highway expansion did. It is, therefore, necessary to utilize a more powerful statistical technique that allows us to consider all the influences simultaneously and will yield test statistics that measure the significance of the influences.

4.5 Statistical Analysis of Land Use Impacts: Procedure

Regressions are estimated using ordinary least squares (OLS) for each of the dependent variables described earlier. A number of different models and functional relationships are investigated and their statistical performance compared. All are estimated on the data described above, which are organized into a "panel" -- a combination of cross-sectional and time series data. The panel is created by stacking the data by region so the variables vary across regions as well as over time. Models could be estimated separately for each region and tests for statistical differences in coefficients across regions conducted. Our focus, however, is to examine the extent to which freeway capacity expansion in general has a statistically significant impact on land use. Therefore, the empirical investigation concentrates on the entire set of data, using dummy variables to control for persistent differences between corridors.

Several different functional forms, including linear and log-linear models, and combinations of variables are investigated Statistical testing clearly shows that the log-linear model is superior for all dependent variables. The preferred log-linear model has the form:

$$\begin{aligned}\ln L_{ikt} = \lambda_i + \alpha_{ik} + \sum_j \beta_{ij} \ln X_{jkt} + \\ \sum_l \delta_{il} D_{lkt} + \sum_{m=1}^{2} \sum_{n=0}^{N} \gamma_{imn} C_{mkt} \Delta t_{mkt}^{n} + \epsilon_{ikt}\end{aligned} \qquad (1)$$

where:

L_{ikt}	is the land use variable for land use i in corridor k in year t (i=1 for single family housing, i=2 for family housing, i=3 for commercial development, and i=4 for industrial development);
X_{jkt}	are continuous independent variables;
D_{lkt}	are dummy variables;

C_{mkt}	are capacity expansion dummy variables (m=1 for the first expansion and m=2 for the second expansion);
Δt_{mkt}	is the maximum of the number of years since completion of capacity expansion m and 0;
$\lambda_i, \alpha_{ik}, \beta_{ij}, \delta_{il}, \gamma_{imn}$	are parameters to be estimated;
ε_{ikt}	is an error term assumed to be normally, identically, and independently distributed

Four different dependent variables are used in the empirical analysis. Two are related to residential land use, one to commercial land use, and the other to industrial land use The residential variables are the annual number of single family housing units for which permits were granted in year t for corridor k and the annual number of permitted multi-family housing units in year t for corridor k. The commercial land use variable is (real) dollar cost of commercial construction for which permits were granted in year t in corridor k and the industrial land use variable is the (real) dollar cost of permitted industrial construction in year t in corridor k. The cost of new construction is used as a proxy since physical measures (such as floor area) are not available for non-residential development. The construction cost measures the extent of new commercial (or industrial) activity and is correlated with the amount of land devoted to that purpose as well as the intensity of development. The dependent variables are normalized by dividing through each of the corridor values by the corresponding value of the variable for the entire region in order to control for factors -- such as macroeconomic variables -- expected to exert a regionwide influence on development activity.

The coefficients of primary interest in the model are the γ_{imn}. These coefficients specify a polynomial of degree N in Δt that characterizes the impact of the mth capacity expansion in a corridor (m=1 or 2) on the ith type of land use (i=1,2,3, or 4). Consider, for example, the coefficient γ_{110}. This coefficient pertains to the impact of an initial capacity expansion (m=1) on single family housing (i=1). Furthermore, since n=0, the coefficient measures a shift in permit activity that occurs just after the expansion occurs and remains constant through time. Similarly, the coefficient γ_{211} pertains to the impact of an initial capacity expansion (m=1) on multi-family housing development (i=2). In this case, n=1, so the impact is one whose magnitude (whether positive or negative) increases linearly with time since completion of the expansion project (Δt). In theory, a polynomial of sufficient order can closely approximate any "well-behaved" dynamic response of a land use variable to a capacity expansion. In practice, we found statistically significant coefficients only for n=0,1, and (in the case of commercial development only) 2. This does not mean that responses are in fact characterized by first (or second) order polynomials, but rather that the information available is sufficient to estimate only a first (or second) order approximation of the "true" response.

A number of the independent variables in our model are highly correlated. Rather than run large numbers of regressions with different combinations of variables and select the "best" one in some ad hoc way, we use principal components analysis to select the subset of variables to be included in the regressions. Principal components is a multivariate statistical technique that analyzes intercorrelations among variables; how variables jointly "hang together."[5] The goal of principal components is to summarize a multivariate data set in a small number of components thereby eliminating variables whose contribution to the explanation of the variation is negligible. This was, therefore, a useful technique to screen our large set of independent variables and choose a subset for the subsequent regressions.

4.6 Statistical Analysis of Land Use Impacts: Results

The results of four regressions are reported below in Tables 4-2 through 4-6; one for each of the four dependent variables. Table 4-2 contains the results for single family housing permits ($i=1$). The regression equation fits well, in a statistical sense, explaining 82 per cent of the variation in the dependent variable based on the adjusted R^2 statistic. As in most of the models, the response is approximated by a first order polynomial in Δt -- higher order terms are statistically insignificant.

Our primary interest is in the γ coefficients since these characterize the impact of capacity expansion on development activity. However, it is useful to briefly discuss the results for some of the other variables in the regression equation. A few variables are not statistically significant including three of the corridor dummies, the population capacity variable, PCAP, the relative

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[5] Principal components differs from regression in that regression is concerned with prediction

Table 4-2.
Dependent Variable: Corridor Share of Single Family Housing Permits (Housing Units)

VARIABLE	OLS ESTIMATE	STANDARD ERROR	T STATISTIC	ASSOCIATED VARIABLE
λ_1	-6.60	2.84	-2.32	Constant for Single Family Housing
α_{11}	0.51	0.32	1.61	Dummy variable Corridor 1
α_{12}	-0.74	0.42	-1.76	Dummy variable Corridor 2
α_{13}	-1.88	0.56	-3.35	Dummy variable Corridor 3
α_{14}	-0.36	0.43	-0.85	Dummy variable Corridor 4
α_{15}	-0.33	0.52	-0.63	Dummy variable Corridor 5
α_{16}	-1.49	0.45	-3.34	Dummy variable Corridor 6
α_{17}	-0.45	0.25	-1.78	Dummy variable Corridor 7
α_{18}	0.00	--	--	Dummy variable Corridor 8 (Forced to 0)
β_{1PCAP}	0.33	0.24	1.34	Population Capacity
β_{1GPR}	-0.52	0.26	-2.04	Gasoline Price Index
β_{1INC}	0.19	0.15	1.26	Income in Corridor/Income in Region
δ_{1DC1}	0.84	0.21	3.90	First City Incorporation Dummy
δ_{1DC2}	0.03	0.21	0.14	Second City Incorportation Dummy
δ_{1FRZ}	-0.94	0.26	-3.56	I-580 Development Freeze Dummy
δ_{1CAP}	-0.80	0.29	-2.75	I-580 Development Cap Dummy
γ_{110}	0.40	0.14	2.83	Dummy for Years after First Capacity Expansion
γ_{120}	0.40	0.20	1.98	Dummy for Years after Second Capacity Expansion
γ_{111}	-0.04	0.02	-2.54	Number of Years after First Capacity Expansion (0 if before)
γ_{121}	0.05	0.03	1.68	Number of Years after Second Capacity Expansion (0 if before)

Number of Observations 192
Adjusted R^2 = .81
Standard Error = 0.54

Table 4-3
Dependent Variable: Corridor Share of Multi-family Housing Permits (Housing Units)

VARIABLE	OLS ESTIMATE	STANDARD ERROR	T STATISTIC	ASSOCIATED VARIABLE
λ_2	-6.15	4.08	-1.51	Constant for Multi-family Housing
α_{21}	-1.02	0.45	-2.25	Dummy variable Corridor 1
α_{22}	-0.50	0.61	0.83	Dummy variable Corridor 2
α_{23}	-1.70	0.80	-2.11	Dummy variable Corridor 3
α_{24}	-1.60	0.62	-2.58	Dummy variable Corridor 4
α_{25}	-1.49	0.75	-1.98	Dummy variable Corridor 5
α_{26}	-3.30	0.64	-5.17	Dummy variable Corridor 6
α_{27}	-0.86	0.36	-2.38	Dummy variable Corridor 7
α_{28}	0.00	--	--	Dummy variable Corridor 8 (Forced to 0)
β_{2PCAP}	0.32	0.35	0.92	Population Capacity
β_{2GPR}	-0.83	0.37	-2.25	Gasoline Price Index
β_{2INC}	0.07	0.22	0.34	Income in Corridor/Income in Region
δ_{2DC1}	0.79	0.31	2.57	First City Incorporation Dummy
δ_{2DC2}	-0.06	0.30	-0.21	Second City Incorportation Dummy
δ_{2FRZ}	0.12	0.38	0.31	I-580 Development Freeze Dummy
δ_{2CAP}	-0.33	0.42	-0.78	I-580 Development Cap Dummy
γ_{210}	0.45	0.20	2.21	Dummy for Years after First Capacity Expansion
γ_{220}	0.09	0.29	0.30	Dummy for Years after Second Capacity Expansion
γ_{211}	-0.08	0.02	-3.17	Number of Years after First Capacity Expansion (0 if before)
γ_{221}	0.17	0.04	3.79	Number of Years after Second Capacity Expansion (0 if before)

Number of Observations 192
Adjusted R^2 = .67
Standard Error = 0.74

Table 4-4.
Dependent Variable: Corridor Share of Commercial Building Permits
(Cost of Construction)

VARIABLE	OLS ESTIMATE	STANDARD ERROR	T STATISTIC	ASSOCIATED VARIABLE
λ_3	-4.09	4.50	-0.91	Constant for Commercial Development
α_{31}	-1.34	0.52	-2.58	Dummy variable Corridor 1
α_{32}	-1.69	0.60	-2.81	Dummy variable Corridor 2
α_{33}	-2.55	0.78	-3.23	Dummy variable Corridor 3
α_{34}	-0.91	0.63	-1.45	Dummy variable Corridor 4
α_{35}	-1.46	0.77	-1.88	Dummy variable Corridor 5
α_{36}	-3.93	0.74	-5.30	Dummy variable Corridor 6
α_{37}	-0.12	0.51	-0.23	Dummy variable Corridor 7
α_{38}	0.00	--	--	Dummy variable Corridor 8 (Forced to 0)
β_{3PCAP}	-0.02	0.38	-0.05	Population Capacity
β_{3GPR}	-0.04	0.41	-0.10	Gasoline Price Index
β_{3INC}	-0.11	0.22	-0.51	Income in Corridor/Income in Region
δ_{3DC1}	0.58	0.46	1.23	First City Incorporation Dummy
δ_{3DC2}	-0.33	0.31	-1.05	Second City Incorportation Dummy
δ_{3FRZ}	0.96	0.45	2.11	I-580 Development Freeze Dummy
δ_{3CAP}	0.46	0.44	1.04	I-580 Development Cap Dummy
γ_{310}	0.59	0.22	2.70	Dummy for Years after First Capacity Expansion
γ_{320}	-0.45	0.33	-1.35	Dummy for Years after Second Capacity Expansion
γ_{311}	0.15	0.02	-2.54	Number of Years after First Capacity Expansion (0 if before)
γ_{321}	0.05	0.03	1.68	Number of Years after Second Capacity Expansion (0 if before)
γ_{312}	-0.01	0.003	-2.31	Number of Years after Second Capacity Expansion, Squared (0 if before)
γ_{322}	-0.01	0.009	-1.26	Number of Years after Second Capacity Expansion, Squared (0 if before)

Number of Observations 168
Adjusted R^2 = .74
Standard Error = 0.74

Table 4-5.
Dependent Variable: Corridor Share of Industrial Building Permits (Cost of Construction)

VARIABLE	OLS ESTIMATE	STANDARD ERROR	T STATISTIC	ASSOCIATED VARIABLE
λ_4	-4.75	6.72	-0.71	Constant for Industrial Development
α_{41}	0.29	0.73	0.40	Dummy variable Corridor 1
α_{42}	-4.51	0.98	-4.57	Dummy variable Corridor 2
α_{43}	-3.71	1.17	-3.17	Dummy variable Corridor 3
α_{44}	-1.42	0.89	-1.59	Dummy variable Corridor 4
α_{45}	-0.14	1.07	-0.12	Dummy variable Corridor 5
α_{46}	-3.20	1.01	-3.20	Dummy variable Corridor 6
α_{47}	1.82	0.69	2.64	Dummy variable Corridor 7
α_{48}	0.00	--	--	Dummy variable Corridor 8 (Forced to 0)
β_{4PCAP}	0.06	0.57	0.11	Population Capacity
β_{4GPR}	-0.25	0.57	-0.04	Gasoline Price Index
β_{4INC}	-0.09	0.29	-0.32	Income in Corridor/Income in Region
δ_{4DC1}	-0.66	0.59	-1.09	First City Incorporation Dummy
δ_{4DC2}	0.67	0.42	1.58	Second City Incorportation Dummy
δ_{4FRZ}	-0.23	0.61	-0.37	I-580 Development Freeze Dummy
δ_{4CAP}	-0.48	0.61	-0.78	I-580 Development Cap Dummy
γ_{410}	-0.09	0.31	-0.29	Dummy for Years after First Capacity Expansion
γ_{420}	0.53	0.44	1.21	Dummy for Years after Second Capacity Expansion
γ_{411}	0.09	0.04	2.19	Number of Years after First Capacity Expansion (0 if before)
γ_{421}	0.13	0.06	1.87	Number of Years after Second Capacity Expansion (0 if before)

Number of Observations 135
Adjusted R^2 = .76
Standard Error = 0.97

income variable, INC, and one of the dummy variables for cities entering the data set in the period of observation, DC1. On the whole, however, the coefficients are quite significant.

The corridor dummy variables, CORRD1-CORRD8, are designed to capture differences between the several corridors used in the study. They enter as 0,1 dummy variables and their coefficient values are added to the value of the constant term when using the regression equation to predict the share of single family housing permit approvals for a particular corridor; in effect, they act to shift the regression equation up or down depending upon their sign. All corridor dummies except CORRD1 have a negative sign meaning the constant term in the equation must be adjusted downward to obtain an accurate prediction of the dependent variable for a particular corridor.

The gasoline price variable, GPR, is of the expected sign and statistically significant. A rise in the price of gasoline appears to decelerate construction of single family homes in the corridor Our explanation for this result is that development in the corridors considered in our analysis is likely to be more automobile-dependent than development in the regions in general. Consequently, when high gasoline prices increase the cost of automobile travel, the corridors become less attractive to residential development.

The dummy variables that capture the land development controls in the I-580 corridor are also significant. As expected both are negative, indicating that controls did what they were designed to do: reduce the rate of development. As structured in this model, the dummy variables would serve to shift the I-580 corridor share downward for the years the controls are in effect.

For the single family housing model, all four capacity enhancement variables are statistically significant at the 10 per cent level, and three -- γ_{121} is the exception -- are significant at the 5 per cent level. The estimates for γ_{110} and γ_{120} positive and of the same magnitude. The positive value indicates that capacity enhancement leads to an initial upward shift in the corridor share of single family home permit approvals. The estimates of γ_{111} and γ_{121} are also significant but of opposite sign, the former being negative while the latter is positive. The former result implies that after the initial capacity increase and consequent upward shift in the corridor share of single family housing development, this share decreases with time. However, if there is a subsequent capacity expansion, it causes not only an upward shift in the corridor share of single family housing development, since γ_{120} is positive, but also an upward trend in this share, since γ_{121} positive.

The impacts of a capacity enhancement project can be interpreted in the following way. At some point t, 1975 for example, the proportion of single family home permits issued for the corridor relative to that in the region has some value. An initial capacity enhancement project is then completed. This may be 1978, for example. From the regression of the impact on single family home permits, the corridor share of permits for single family homes increases by an amount given by $\exp(\gamma_{110})-1$, or 49 per cent.[6] The negative value of γ_{111} implies that the impact of the capacity expansion diminishes with time If the project has no additional phases this is the end of the story. If, however, there is an additional expansion, the positive sign of the γ_{120} estimate implies that the corridor share of permits is shifted upward still further. Since, however, the γ_{121} is positive (although of marginal significance statistically), the impact of a second expansion project seems to grow (or at least persist) over time.

The main conclusion from the analysis of permits for single family housing construction is that capacity enhancement encourages this form of development. The completion of an initial capacity enhancement results an initial surge in permits issued for single family homes, but this impact subsides in succeeding years. If there is an additional capacity enhancement, this results in a further, and sustained, increase in single family home permit activity.[7]

Table 4-3 contains the empirical estimates for multi-family housing (i=2). Before examining the project impact variables, it is useful to look over the other variables and model as a whole and compare it to that of single family homes (Table 4-2). First, it is clear that the multi-family housing model has less explanatory power, its adjusted R^2 is .67 as compared with .82 for the single family model. This implies that variables excluded from the models have a

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[6] To see this, recall that the dependent variable is the natural log of the corridor permit share According to the results, completion of an expansion increases this function by 0 4 Adding 0 4 to the natural log of a variable is equivalent to multiplying that variable by exp(0 4), which is approximately 1 49.

[7] However, permit activity after the second expansion is assumed to be affected by the first expansion as well Since γ_{111} is negative and greater in magnitude than γ_{121}, there will continue to be a downward trend in corridor permit share after the second expansion The impact of the second expansion is "sustained" in the sense that (according to the model) in every year after the second capacity expansion, permit activity is greater than it would have been without this expansion This is true even though the cumulative impact of both expansions diminishes with time

stronger effect on development activity involving multi-family units. The corridor dummy variables are significant except the coefficient on CORRD2. Other variables such as gas price have the expected negative sign and are significant. The coefficient on the dummy variables for the I-580 land development freeze and subsequent cap are not significant. This is an interesting result since it implies that the development freeze instituted by the City of Pleasanton did not affect multi-family housing development, as it did in the single family case.

The important results are, as before, the γ estimates. The results for these variables differ from those for single family homes, demonstrating that it is important to distinguish housing by type. The constant response coefficient for the first capacity enhancement, γ_{210}, is positive, significant, and of similar magnitude as that in the single family housing model (γ_{110}). This implies that the first capacity enhancement on a corridor stimulates family permit activity. Unlike the single family case, however, the estimate for γ_{220} is not statistically significant, implying that a second capacity expansion does not immediately stimulate family housing development. The coefficients γ_{211} and γ_{221} have the same signs but double the magnitudes of their single family housing counterparts, γ_{111} and γ_{121}, suggesting that capacity expansions strongly effect trends in corridor family permit activity, but that the direction of these effects varies depending on whether the expansion is an initial or a subsequent one.

The interpretation of the land use effect for multi-family home permit approvals is the following. At completion of the initial capacity expansion, there is a significant impact on land use with a sudden increase in the corridor share of multi-family housing permit approvals. This impact dissipates over time, however, since the corridor permit share decreases with time since project completion. After completion of a second capacity enhancement project on the same corridor, if this occurs, there is no sharp upward shift in permit approvals, but the corridor share of permits increases gradually with time, since γ_{121} is positive. The main conclusion, however, is not in these details, but rather that a capacity enhancement stimulates multi-family housing development, as it does single family housing.

Much of the literature on the land use impact of transportation investment and capacity expansion has focussed upon non-residential property effects. In our analysis, the non-residential impact is measured by the cost of permitted commercial ($i=3$) and industrial ($i=4$) construction. Our regressions for the corridor share of commercial and industrial permit activity are contained in Tables 4-4 and 4-5, respectively. In both models, significant variables are restricted to certain corridor dummy variables and certain capacity expansion variables The models also have comparable adjusted R^2 values -- .67 in the case of the commercial model and .76 for the industrial.

According to the estimation results, an initial capacity enhancement has a statistically significant positive impact on the corridor share of new commercial construction (γ_{310}=0 59). Furthermore, the effect rises over time as the γ_{311} is positive and significant, but it does so at a decreasing rate, since γ_{312} is negative. If there is a second enhancement project on the same corridor, it reduces the impact of the initial enhancement by shifting the corridor share of commercial permit activity downward (γ_{320}=-0.45), but after a couple of years the effect turns positive by virtue of the positive γ_{321} estimate of 0.17.

The impact of an enhancement project on industrial permit activity (again measured in terms of construction cost) contrasts to that on commercial activity. First, the completion of an initial capacity enhancement project has no immediate effect on the pace of land development for industrial use: as shown in Table 4-5, the γ_{410} estimate is statistically insignificant However, an initial capacity increase spurs an upward trend in the corridor share of industrial development, since the γ_{411} estimate is positive and significant. The estimated impacts of a second expansion, if one occurs, parallel those of the first γ_{420} is not significant, implying that there is not an immediate upward shift, but γ_{421} is (marginally) significant, suggesting that the corridor share of industrial permit activity begins to trend upward after the expansion is completed.

4.7 Summary and Conclusions

There are three schools of thought regarding the impact that highway capacity expansion has on land use. One maintains that building roadways, or expanding existing ones, results in additional land development. A second school contends that such highway investments have no net impact, but rather temporarily changes the rate of development, moving forward in time something that would have taken place at some future date. The third school asserts that expanding roadways have no effect on land use, that transportation is a derived demand and that land use changes occur independently of any expansion. The empirical work presented in this chapter provides support for the first and second schools, but does not conclusively indicate which of these is the more correct.

Our research has investigated, using a panel of data, the impact of highway capacity expansion in a number of corridors located in major urban areas of California. The data set contained variation across corridors as well as time and represents as careful an attempt as possible to test land use impact hypotheses in a rigorous statistical way Four dependent variables are considered, based on construction permits for single and multi-family housing units, for commercial construction, and for industrial development. A number of additional variables are introduced in an attempt to distinguish the impact of a highway capacity increase from land use changes resulting from other factors.

We have found that highway capacity expansion has a strong and statistically significant effect on both residential and non-residential land use. We found that capacity enhancement has the effect of increasing the number of single family housing permits in the affected corridor relative to the level in the region. If a second expansion occurs on the same corridor, its impact is similar to the first. In either case, after an initial upward "shift" in single family home permits in the corridor relative to the region, the share gradually declines. This suggests that development moves forward in time but may not increase in the aggregate. The results for multi-family housing permits are similar. Again, there is a significant upward shift in corridor permit shares that dissipates over time. In the case of multi-family housing, however, a second capacity expansion on the same corridor yields a different impact -- there is not a sudden upward shift, but corridor permits shares do start to trend upward after the expansion is completed.

Non-residential land use changes are examined using estimated cost of permitted commercial and industrial construction. The results for these two types of development contrast. Capacity enhancement is found to have an immediate impact on commercial but not on industrial land use. In the case of the former, there is an upward shift in corridor share of permit activity after completion of an initial capacity enhancement but not after completion of a second expansion. In either case, the enhancement also triggers a trend toward higher corridor permit shares. The impact of a capacity addition on industrial land use occurs only after the initial expansion and takes the form of a gradual increase in corridor development.

By necessity, our analysis has depicted the land use impacts of highway capacity expansion in considerable detail. We have differentiated among development types, between initial and subsequent capacity expansions, and between impacts that take the form of abrupt shifts and those that build over time. Our results suggest that these distinctions are important· highway capacity expansions have different impacts on different types of development, impacts of initial and subsequent expansions differ, and impacts may include both sudden shifts and more gradual trends. However, we also recognize that the statistical analyses on which our findings are subject to uncertainty, and that some of our more detailed findings rest on fairly small number of observations. While we acknowledge considerable uncertainty over these details, our results offer strong support for one overriding conclusion: highway capacity expansion stimulates development activity, both residential and non-residential, in the corridors served by the expanded facilities.

References -- Chapter 4

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Chapter 5:

Land Development Impacts: Case Studies

5.1 Introduction

In this chapter, case study analysis is used to assess land use impacts of highway capacity expansions at the corridor level, where a "corridor" is defined as a grouping of communities adjacent to the improved facility. The primary research question framing this chapter is whether the highway expansion projects were a significant causal factor in the growth rates of the communities along the facility, in other words, did the highway projects induce growth? The case studies include several elements. First, we documented trends in growth and development of the communities directly served by an expanded highway facility. Second, we investigate the communities' development policies, focussing on whether and how they relate development to freeway congestion levels. Finally, we interview land developers with projects in the corridor communities to determine if and how the capacity enhancement influenced these projects.

In examining the impact of highway capacity expansions on growth and development of the surrounding communities, this chapter overlaps with Chapter 4. The methodology is, however, entirely different Whereas Chapter 4 is concerned with statistical relationships between building permit activity and highway expansion, here our approach is more qualitative. It is designed to provide a detailed picture of the factors, including but not limited to highway capacity expansion, influencing development in a set of urban corridors where there have been significant highway capacity expansions in the last two decades. Thus, while Chapter 4 poses the question "Does highway expansion stimulate land development?" the question considered in this chapter is "What is the complex of forces that influence land development, and how does highway expansion fit into this complex?" To explore this question, we rely primarily on interviews with and documentation from key actors in the land development process, including developers themselves and local planning agencies. This implies a second important difference with Chapter 4. Whereas the results of the latter rest on formal statistical tests, our findings in this chapter are based on the perceptions of key actors. The relation between, and relative credibility of, these two types of evidence is a source of continuing philosophical and scientific debate. As will be seen below, this issue is of no small concern to the present study, since the results of the statistical analyses and case studies seem to conflict substantially.

Specifically, the results of our case study analysis appear to discount the influence of highway capacity expansions in accelerating growth in the surrounding area. The city planners and real estate developers interviewed for these case studies believe that the highway expansion projects in their regions were of relatively minor importance in stimulating development The general consensus among these professionals is that growth rates would have been comparable in the absence of the highway expansion Factors identified as more important to the growth of these areas are their attractive quality of life and moderate housing prices.

5.2 Research Methodology

A case study corridor is selected in each of California's four major metropolitan regions: San Francisco, Sacramento, Los Angeles, and San Diego. Using Caltrans financial reports, we identify one major freeway facility in each of these regions which had a capacity-increasing expansion project sometime during the period 1970-1990

The case study analysis includes a review of documents, such as general plans and growth management reports, related to the development of communities in these corridors, as well as discussions with planners familiar with growth patterns in the case study regions In addition, we interview real estate developers who built projects in the San Francisco Bay Area along the improved I-580 corridor to elucidate developers' perspectives on the interaction between land development and transportation improvements.

Most of the communities included in the study can be characterized as bedroom suburbs that provide housing for people working in the region's central cities. For this reason, housing demand at the regional level is generally cited as the primary factor influencing development in the communities studied. Once job growth attracts people to the region, the search for housing begins at the sub-regional level as families determine which communities offer homes in their price range. According to Von Thunen's model of the bid-rent function (Sullivan.1990), as one moves out from the center, the price of housing falls and transportation costs (as measured by distance or time) increase, keeping the sum of housing and transportation costs constant. A freeway widening project that is designed to reduce congestion will speed the flow of traffic, thereby reducing overall travel times. The addition of capacity on freeways would thus appear to make land in outlying areas more valuable, and thus stimulate their development. The case studies attempt to determine whether this phenomenon in fact occurred in the subject corridors, and assess its significance relative to other factors

5.3 Land Planning and Development Trends

5.3.1 Introduction

This portion of the case study analysis involves a detailed examination of the growth and development of selected communities along the improved highway corridors. The analysis focusses on one or two cities from each case study corridor and identified in Table 5-1 below. Interviews are conducted with people familiar with the development history of each community. We also review related planning documents and research reports in order to gain an understanding of the forces shaping growth in the corridor cities.

The purpose of this portion of the study is to determine if any causal connection exists between the widening projects and the pace of growth and development in the adjacent communities, as seen from a planning point of view. None of the planners interviewed believe that the capacity expansion of the adjacent freeway directly accelerated the growth of their city, or that growth would somehow have been hindered in the absence of the improvement.

In applying these findings to other situations, one must keep in mind at least two limitations. Firstly, planners may consider only direct effects of highway expansion and may not be aware of any indirect impacts In addition, the case studies look at situations where the highway was actually expanded, and these cannot be directly compared to scenarios in which the expansion did not occur. The case study methodology, while generating very detailed information about the growth that has occurred, cannot make precise arguments about hypothetical situations. At the building permit approval stage, most planners interviewed state that they do not deny project approvals based on traffic impacts on the freeways Whether the approval policy would be different in this regard if the freeway improvement had not occurred is speculative.

Table 5-1.
Case Study Cities and Planners Interviewed

Case study region	Cities selected	Persons interviewed
San Francisco	Pleasanton	Brian Swift, Planning Director
Sacramento	Auburn Rocklin	Bret Finning, Assistant Planner Kay Berryman, Associate Planner
Los Angeles	Oxnard Ventura	Matthew Winegar, City Planner Mark Stephens, Senior Planner
San Diego	Escondido San Marcos	Barbara Redlitz, Principal Planner David Acuff, Associate Planner

5.3.2 Case 1: San Francisco Area -- I-580

The corridor chosen for the first case study is I-580 between Pleasanton and Hayward in Alameda County, as shown in Figure 5-1. This segment was expanded from 4 to 8 lanes. The widening occurred in three phases, progressing from east to west, with the first phase completed in 1975 and the last in 1988. Planning for the project began in the 1960s. In the early 1970s, it was modified to include a 90 ft median to accommodate a Bay Area Rapid Transit (BART) extension, which is currently under construction.

Pleasanton is located immediately south of Interstate 580, in the vicinity of the I-580/I-680 interchange in the Livermore Valley. These two freeways provide access to Bay Area population and employment centers to the north, west and south, and connect with growing residential areas of the San Joaquin Valley to the east. The City of Pleasanton is an interesting case because it has become a major suburban employment center, while continuing to attract residential development.

The City of Pleasanton was a sleepy agricultural community until around the end of World War II. Then single family subdivisions began to spring up in the Livermore and adjacent Amador and San Ramon valleys, making Pleasanton one of the fastest growing cities in the state in the 1960s (LeGates and Pellerin, 1989) The haphazard growth of that decade placed excessive demand on the sewage system serving the area, threatening the quality of the water supply. This lead to a moratorium on growth in Pleasanton in 1972 by the Regional Water Quality Control Board (General Plan Supplement, 1976). Air quality in the valley area also deteriorated with the rapid growth.

Development of residential projects restarted with a cap of 2 per cent growth per year in 1976, when federally-assisted financing for a new sewage treatment plant was obtained. The residential growth cap, calculated based on sewer capacity, was made a condition of the federal funding (Growth Management Program, 1991) Population growth has generally exceeded the estimates, rising from 35,160 persons in 1980 to a population of 50,553 in 1990. Development in Pleasanton is still controlled through the Growth Management Program.

There was very little nonresidential growth in Pleasanton until the mid-1970s, when rising land prices and office rents in San Francisco and Silicon Valley encouraged businesses to look elsewhere for office space The I-580/I-680 corridor was attractive to Bay Area firms because it offered them room to expand their operations at relatively low land prices. In addition, population

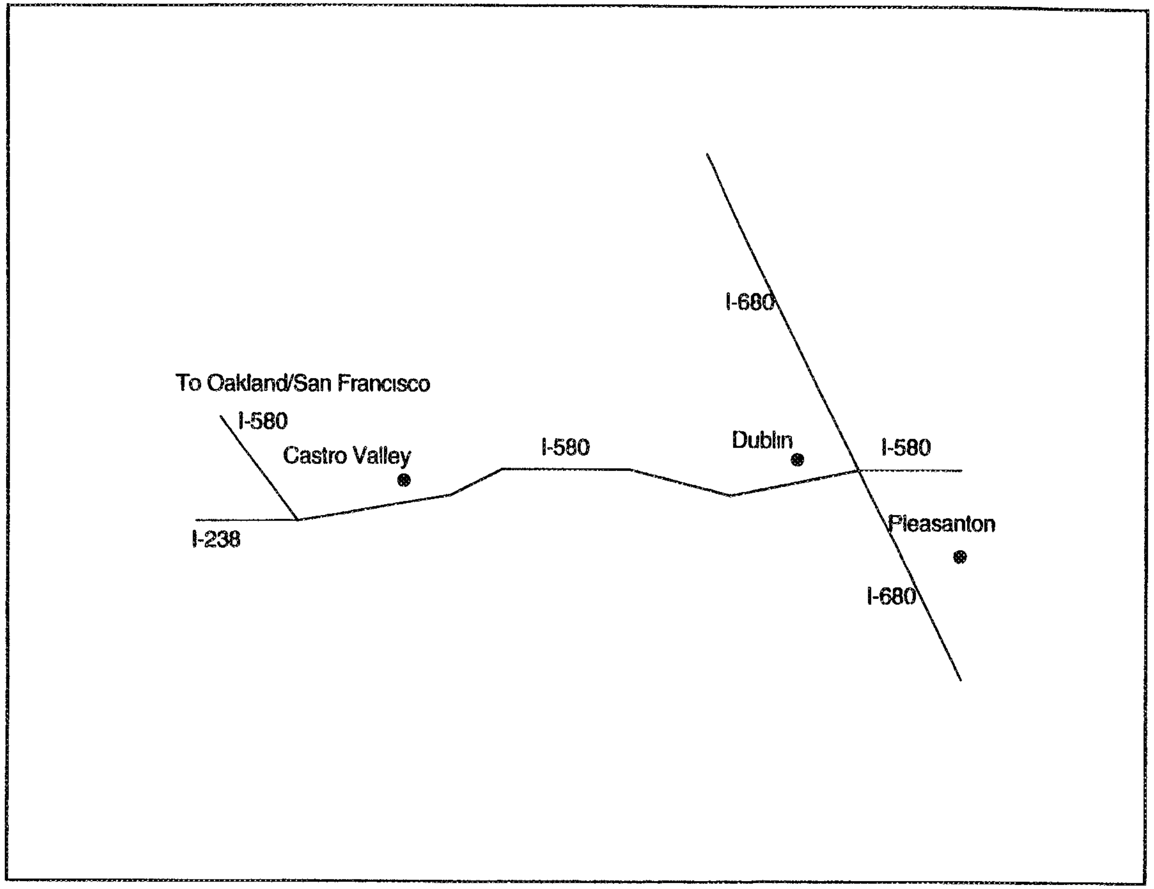

Figure 5-1.
Case Study 1: I-580, San Francisco Bay Area

growth in the Tri-Valley (a term used to refer to the Livermore, Amador, and San Ramon Valleys) had created a large and well-educated labor pool from which Pleasanton businesses could draw employees.[1] Due to its proximity to I-580 and I-680, Pleasanton is also within the 30-minute commute shed of a large percentage of the labor pool residing in Alameda, Contra Costa and San Joaquin counties (Keyser Marston, 1988).

In addition to regional (and state and national) forces outside their control, local governments play an important role in shaping growth in their communities Common controls exercised by local governments over development activities include zoning ordinances, issuance of building permits, and the provision of city services (i.e police and fire protection) and infrastructure (i.e. water and sewer mains, streets and roads) required for acceptable development. In order to assess the impact of local government planning activities on Pleasanton's growth, we review planning documents adopted by the City of Pleasanton over the last three decades, along with various reports documenting Pleasanton's growth An interview with the city's planning director, Brian Swift, supplements these documents.

According to these sources, population growth in the Tri-Valley area has been primarily fueled by a strong regional economy that translated into increased demand for housing. Where the new housing is built depends in large part on the availability and the price of land Rapid escalation of home prices in the Bay Area in the 1970s and 1980s produced a severe undersupply of affordable housing, while the region continued to attract new jobs Housing development for Bay Area workers has spilled into outlying areas in consecutive waves, as land in central communities became built out or too expensive. Planners and developers familiar with the City of Pleasanton generally agree that this phenomenon was the primary cause of the growth in their city.

On a subregional level, the Tri-Valley area was the focus of Bay Area development

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[1] Much of the employment attracted to Pleasanton's business parks involves low-paying 'back office' work Advances in computers and telecommunications have allowed these relatively low-skill technical and clerical positions to move to low-rent facilities away from the centrally located 'front offices', while still being able to communicate with the main office when needed While clerical labor demand is primary, there are other types of back office work, such as research and development, which require little direct contact with the rest of the company or with the extra-corporate world (Nelson, 1986)

because it had large amounts of undeveloped land and was connected to the inner Bay Area by the two major freeways. The freeways were important because they provided access between the new residential developments in the suburbs and jobs located in the central cities. The Pleasanton/Livermore area attracted new population growth in the 1960s and 1970s because its homes were affordable by regional standards and were only twenty to thirty minutes from major employment centers in San Jose and Oakland. Land prices have since escalated in the Tri-Valley area, pushing developers to seek land for affordable housing to the east, in the San Joaquin Valley

The 1976 and 1986 General Plans establish no direct link between transportation investments and growth in the city through the 1970s. Transportation is considered a more important factor in the large scale office development that occurred in the early 1980s. According to the 1986 General Plan, building activity in Pleasanton "can be explained largely by its location within the I-680 corridor (p. I-5)." However, no specific freeway improvement projects (such as the I-580 expansion project) are mentioned as critical in this regard. With respect to transportation improvements, the plan only states the intention to keep traffic moving on city streets at acceptable levels of service, proposing that developers be required to bear a greater share of the cost of roadway improvements (1986 Plan:p.III-12).

The sewer capacity problems of the early 1970s produced a shift in the growth policies of Pleasanton. With restrictions placed on its residential growth, Pleasanton sought to encourage employment-related and other non-residential development that would not exacerbate its water quality and sewage system capacity problems An example of this was the rezoning of an area of approximately 225 acres to the immediate southwest of the I-580/I-680 interchange for a regional shopping center (1976 Plan Supplement· map, p. 6). The history of the shopping center that was built on the site, the Stoneridge Mall, will be discussed in greater detail below.

As Pleasanton directed its growth toward commercial and office development during the 1980s, the city's excellent accessibility enhanced its bid to become a major regional employment center. The ability to offer low rent offices, coupled with a well-educated population and generally uncongested (by Bay Area standards) freeways made the I-680 corridor particularly attractive to business park development (LeGates and Pellerin, 1989 p. 9).

The City of Pleasanton realized that its policies of favoring commercial and office development over residential construction would eventually create a significant discrepancy between the supplies of jobs and housing. The 1986 Plan notes that the city designated land for business park use in locations "convenient to freeways, arterial and transit corridors" to maximize the accessibility of these workplaces for workers living in other communities (p. II-14). It proposed to handle anticipated increases in traffic (resulting from large numbers of these in-commuters) by continued expansion and improvement of its local circulation system.

Significant increases in traffic have prompted proposals to improve several interchanges along I-580. It is hoped that the proposed extension of BART to Livermore will also relieve traffic congestion brought on by recent growth (1986 Plan p III-6). These examples link transportation improvements to development with the improvements *following* the growth.

In conclusion, there is no explicit indication in the city's planning documents that the expansion of I-580 between Hayward and Pleasanton had any direct impact, in and of itself, on the pace of growth in Pleasanton. It does not appear that transportation investment decisions influenced residential and/or non-residential construction trends in this area to any significant extent The evidence suggests that Pleasanton's accessible location would have attracted development interest even if the I-580 expansion had not occurred

5.3.3 Case 2: Sacramento Area -- I-80

The Sacramento area was one of the fastest growing parts of the state during the 1980s, with rapid expansion of the regional economy and high levels of housing construction. The City of Sacramento sits on a flat plain in the Sacramento Valley. Development patterns to the east of the city are influenced by the Sierra foothills, but are generally unconstrained by topography in the other directions.

The project selected for the Sacramento area is I-80 northeast of the city of Sacramento, shown in Figure 5-2. Originally four lanes, this freeway was widened in two projects in the 1970s. The 6-mile segment between Sacramento and Roseville was expanded to six lanes and eight lanes in the eastern and western parts, respectively. This project was programmed in 1970 and completed in 1973. The 15-mile segment between Roseville and Auburn was expanded to six lanes in a project programmed in 1974 and completed in 1975.

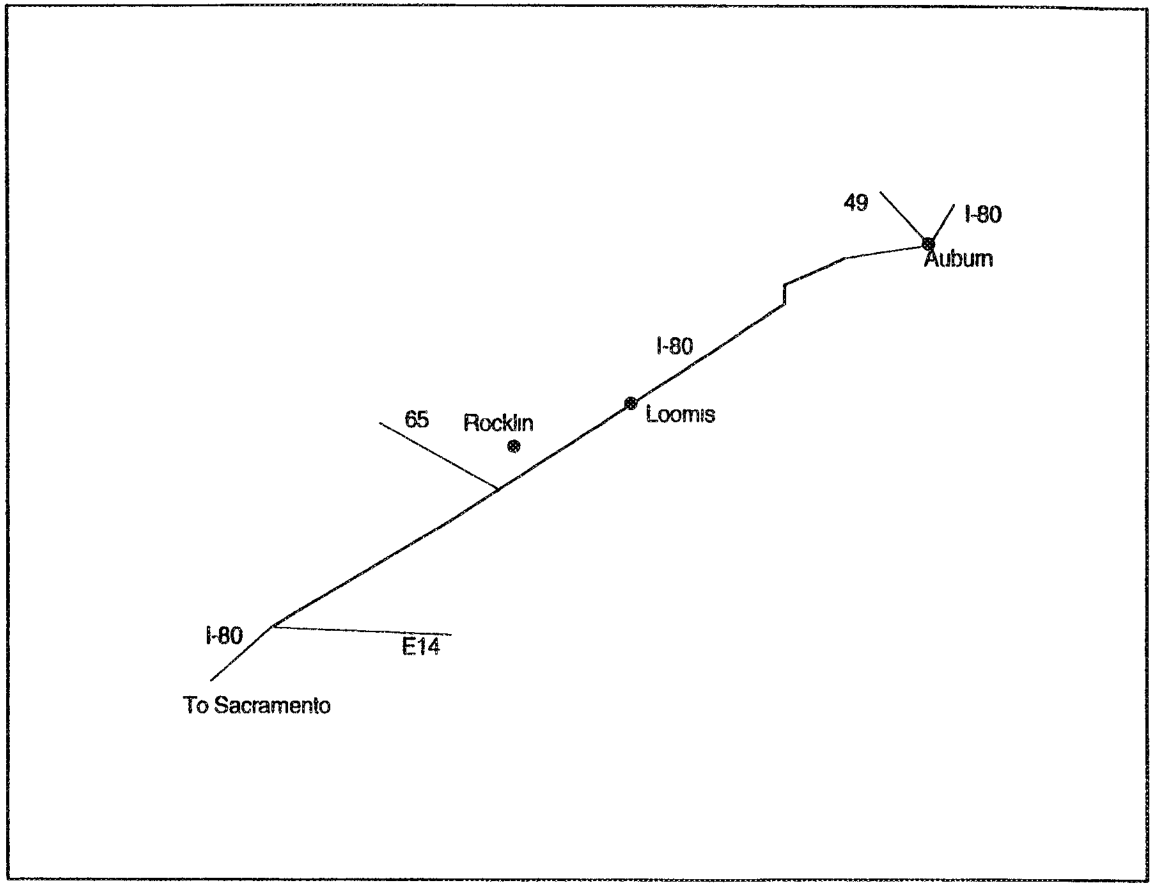

Figure 5-2.
Case Study 2: I-80, Sacramento Area

5.3.3.1 City of Rocklin

The City of Rocklin has a boom/bust history typical of many early western towns. Rocklin was incorporated in 1893, with railroad-related activity encouraging much of the early economic development and population growth in the area. When the major railroad operations moved down the line to Roseville in 1908, Rocklin began to lose jobs and population Over the next twenty years, the city's population fell from 3,500 to about 350. Slowly things began to turn around for Rocklin, and the population grew from 759 residents in 1940 to 1,495 in 1960

In 1960 it was announced that a "new city" called Sunset Whitney would be constructed immediately to the northwest of Rocklin, leading many to predict an upcoming boom in development. Construction of the project began in 1962, but financial difficulties stopped work in 1965. Six years later, construction in Sunset Whitney restarted with new financing, prompting gradual growth in the project area and focussing new attention on nearby Rocklin Substantial growth occurred in Rocklin throughout much of the 1970s, until higher interest rates increased building costs and slowed development toward the end of the decade (Rocklin General Plan, 1991). The Sunset Whitney development, with a population of about 2,000 people, was annexed into the City of Rocklin in 1986. See Table 5-2 for population trends in Rocklin since 1973

The rate of development began to pick up with lower interest rates in the early 1980s. In 1985, the first phase of a major new project in the Rocklin area, the Stanford Ranch, was approved. This 3,245 acre project will eventually contain approximately 11,000 dwelling units, as well as several hundred acres of commercial, industrial and business space (City of Rocklin, 1992). Also planned for the site are parks, schools, a fire station, and a water plant. Most of the land has been annexed into the city but is still in the planning and permitting stage of development. Stanford Ranch is the focus of much of current day development interest in Rocklin. The project site is in the north end of the city, adjacent to State Route 65.

The national recession slowed housing development and population growth in Rocklin to 7.5 per cent in 1992, but for most of the past two decades growth has been at a double-digit pace. According to city planner Kay Berryman, the city has sought strong growth through aggressive marketing. Nearby Loomis, on the other hand, is trying to avoid additional population growth. Residents of this community incorporated in 1986 in order to pursue a slow-growth policy.

Table 5-2.
City of Rocklin Population Trends

Year	Population	Rate	Year	Population	Rate
1973	3,440	11.1%	1983	8,211	2.9%
1974	3,610	4.9%	1984	8,507	3.6%
1975	3,502	-3.0%	1985	9,056	6.5%
1976	4,356	24.4%	1986	9,820	8.4%
1977	5,004	14.9%	1987	12,244	24.7%
1978	5,625	12.4%	1988	13,970	14.1%
1979	6,475	15.1%	1989	15,413	10.3%
1980	7,226	11.6%	1990	18,142	17.7%
1981	7,438	2.9%	1991	21,640	19.3%
1982	7,980	7.3%	1992	23,253	7.5%

Source: City of Rocklin Planning Department

Policies stated in Rocklin's General Plan make it clear that further growth is expected to occur in the future. Projecting an estimated population of 36,238 (moderate growth scenario) or 48,610 (high growth scenario) by 2010, the plan incorporates policies that seek to accommodate growth while avoiding significant environmental impacts. Nevertheless, according to the plan, some environmental impacts have been found to be "significant and unavoidable." These include potential impacts on "...regional air quality ... and the cumulative regional impacts on traffic circulation... (Rocklin General Plan, 1991)."

The Rocklin General Plan discusses several city policies regarding development levels and the circulation system Housing development is encouraged adjacent to existing developed and serviced areas, in order to avoid leap frog development. Another policy seeks to ensure that adequate parking and access are included in approved commercial development plans. Typically, access requirements such as this, often combined with level of service standards for key intersections, refer only to local traffic conditions The city uses a level of service standard of "C" for city streets when considering projects. According to Ms Berryman, the city can require interchange and intersection improvements and local road widenings for larger developments, such as the Stanford Ranch project, that are expected to generate significant traffic and lower the level of service at critical points.

Rocklin decision makers recognize that development within the city increases travel demand on the regional transportation system, but feel that its contribution to traffic levels on I-80 is relatively small Adequate capacity on I-80 has been extremely important to growth in Rocklin because so many residents use the freeway to get to work in Sacramento or Roseville, and there are no viable alternative routes. Developable areas away from I-80 would be less influenced by the freeway congestion than sites adjacent to the freeway. Areas to the north of the city, for example, could use alternate routes to access the freeway at a point below the congestion.

In spite of the importance of maintaining adequate freeway capacity, the city continues to approve new development projects that will increase congestion levels. According to Ms. Berryman, development projects that generate new traffic on I-80 would be equally likely to receive approval by the city whether or not the freeway has the capacity to handle the additional traffic. If capacity is inadequate, future widening projects or investments in alternative transportation facilities are expected to accommodate the new demand.

5.3.3.2 City of Auburn

Historically a small rural community with an independent economy, Auburn now identifies itself as a commuter suburb of Sacramento The city is an "easy drive" from Sacramento jobs -- the trip to downtown Sacramento takes approximately one hour during the commute period. This commute has never been very congested, but significant backups can occur if there is a major accident along the highway because there are no alternate routes. Recreational traffic is very heavy along I-80 because this freeway is the key route to the North Lake Tahoe/Reno area. Commute hour traffic creates bottlenecks at a few interchanges near Sacramento, including Roseville Road and the I-80/Business 80 junction.

Housing development in the Auburn area has mostly been in small projects. In contrast to neighboring Loomis, there has been little local opposition to the growth, perhaps because many of the developers are long-time local residents who are subdividing their own land. The parcels are often sold to people who build their own custom homes -- activity by large out-of-town developers has been sparse

The few large housing subdivisions that have been constructed in Auburn are mostly located along the hillsides in the southern part of town. People purchasing these homes are primarily workers who commute to jobs in Sacramento or Roseville, or retirees from the Bay Area or Los Angeles. Bret Finning, a planner and long-time resident of Auburn, believes that families are attracted to these housing developments because of the good views and nearby freeway access.

In contrast to more established residents, many of the newer families want to limit growth in the city in order to maintain the rural character. While Auburn has no formal growth control policy (i.e. strict limits on the number of housing unit approvals issued each year) some projects have been downsized as a result of community opposition. This action is mainly related to housing construction: for example, plans for a particular development were approved only after its size was reduced from 15 to 10 homes.

The growth rate in Auburn was approximately 2 per cent during the period 1960-1975 The rate of population growth in the city has averaged 3 to 4 per cent more recently (see Table

5-3) Much of the housing development has occurred along narrow country roads with inadequate capacity to handle the additional traffic. Auburn has established a traffic mitigation account and requires developers to pay into the account to fund widening projects throughout the city.

Development in Auburn has often occurred by long-time residents subdividing their land. In addition, the city is willing to annex unincorporated land and provide local public services (fire, police, and sewer) to developments. Water service is provided by an independent agency and appears to be in sufficient supply. Other than the imposition of traffic impact fees, the city does not condition or restrict development on the basis of traffic generation. Auburn has never denied approval to a project based on overloading city streets It is even more unlikely that an otherwise acceptable project would be turned down for generating additional traffic on roadways, such as I-80, that are not under Auburn's jurisdiction.

Because of the rapid growth in Placer County and significant recreational traffic along I-80, much investment has been made to widen and upgrade highways in the area. In addition to the earlier widening of I-80 from Sacramento to Auburn, the freeway was recently widened through the City of Auburn Work on this section, completed in 1990, involved a realignment of the roadway to make the downhill slope safer and make more room for truck travel. This project did not change commute travel times for Auburn residents very much, as they generally access the freeway from the south end of town anyway.

In addition to the recent widening of I-80 mentioned above, improvements are being made to some state highways in the area such as Highways 49 and 174. There is also a proposal for a new freeway facility, Route 102, which has been widely discussed. The proposed freeway would start at I-80 north of Auburn and terminate at I-5 north of Sacramento. This route would bypass all I-80 corridor communities and the traffic congestion in the area. There is a lot of opposition in Placer County to this new route based on feared growth-inducing impacts, and the proposal appears to be inactive at the moment.

5.3.3.3 Conclusions -- Sacramento Area

Generally, the I-80 freeway appears to be important to growth in cities along the corridor. While the level of congestion on the facility has been relatively low, planners in Rocklin and Auburn agreed that increased traffic congestion on I-80 would not cause them to deny building

Table 5-3
City of Auburn Population Trends

Year	Population	Rate
1970	6,570	---
1980	7,540	---
1981	7,707	2.2%
1982	7,994	3.7%
1983	8,258	3.3%
1984	8,511	3.1%
1985	8,723	2.5%
1986	8,863	1.6%
1987	9,002	1.6%
1988	9,218	2.4%
1989	9,844	6.8%
1990	10,592	7.6%
1991	10,894	2.9%
1992	11,156	2.4%

Sources: US Census Bureau, California Department of Finance permits. In both cases, planners that they would have approved projects whether or not I-80 had been expanded. Rocklin appeared to expect that capacity along the corridor would keep up with demand

In the case of Auburn, however, there are indications that inadequate levels of other public services, such as fire protection and sewer service, could influence development levels. In Rocklin, this does not appear to be a problem.

Growth in this corridor has been spurred by escalating housing prices, an increase in crime and traffic, and other problems generally associated with urban areas, which are causing many families to relocate to a more rural atmosphere Many people of retirement age are also selling their homes in the Los Angeles and San Francisco areas and moving to a more rural location. In addition, Mr. Finning (City of Auburn) suggested that the 1989 Loma Prieta earthquake may have encouraged some San Francisco Bay Area residents to move out to the country.

Nonresidential construction has been attracted by the transportation network in Placer County. Industrial parks in both Rocklin and Auburn are well-oriented to both rail and highway facilities. The completion of the Highway 65 bypass in Rocklin "accelerated development of the area," by facilitating deliveries to business and industry (Rocklin, 1988). In addition, deep water ports and international air transportation are available nearby in Sacramento. There is also a small airport in Auburn.

Conditions on the I-80 freeway are important to the communities that it serves because there are no alternate routes. While there are daily bottlenecks at busy interchanges, this freeway experiences little traffic congestion unless there is an accident. Continued job growth in the Sacramento is expected to bring new commuters to I-80 corridor communities The high quality of life in the area will also continue to attract retirees from other parts of the state.

5.3.4 Case 3: Los Angeles Area -- Route 101

Route 101 in Los Angeles and Ventura Counties, shown in Figure 5-3, was selected for the Los Angeles area case study. Several widening projects have occurred on the road over the past two decades. The portion in Los Angeles county was expanded from 4 to 8 lanes in a project programmed in 1971 and completed in 1974 A three-phase expansion of the Ventura portion of

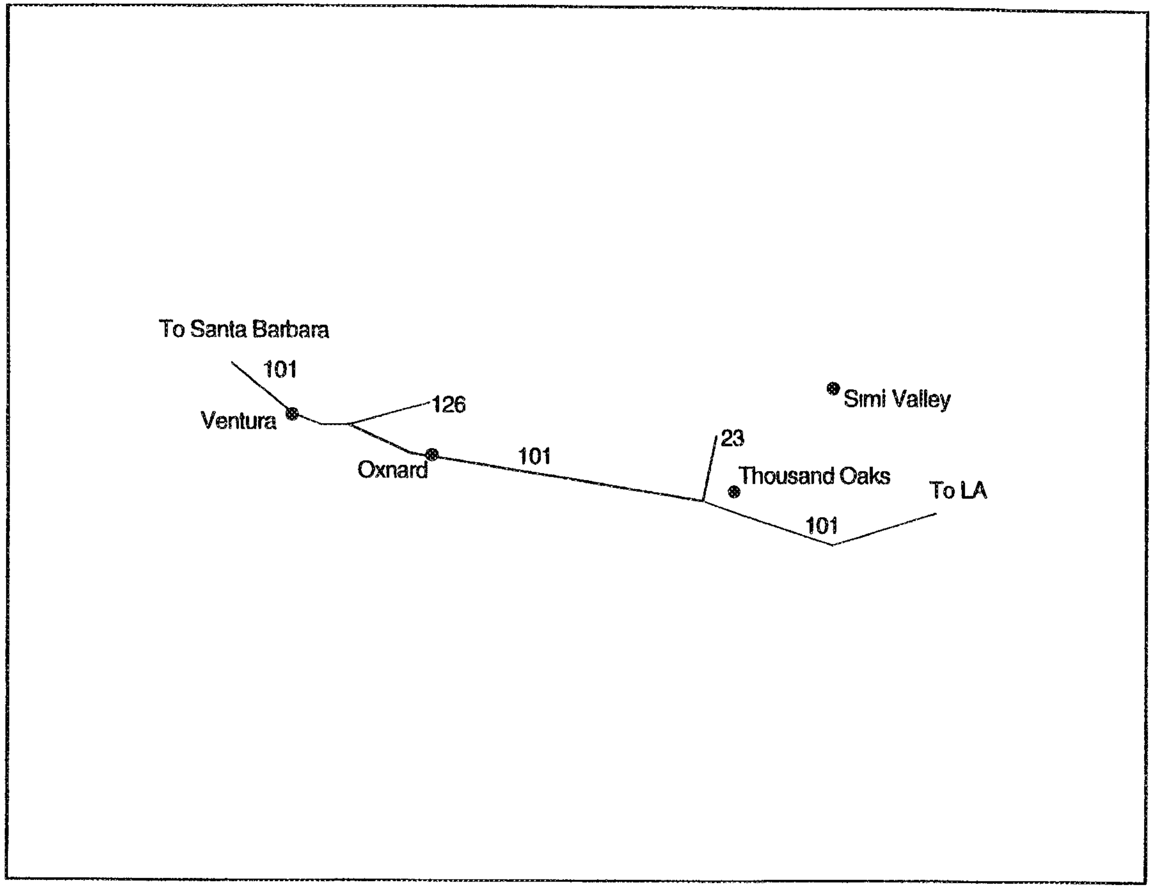

Figure 5-3.
Case Study 3· Route 101, Los Angeles Area

Route 101 was programmed in 1980 and completed in 1988. The project included a 5-mile section from the Los Angeles County line to Conejo summit that was expanded from four to eight lanes, and a 15-mile section north of this, ending at the junction with the Pacific Coast Highway, that was widened from four to six lanes.

The cities of Ventura and Oxnard are located in Ventura County along Highway 101. These two coastal cities dominate the western half of the county Oxnard is located at the junction of Highways 101 and 1, and Ventura immediately to its northwest Development of eastern Ventura County has occurred predominately in the cities of Simi Valley and Thousand Oaks. These latter two cities are only a few miles from the Los Angeles County border, and thus are more closely linked to growth in Los Angeles than communities farther west

5.3.4.1 City of San Buenaventura (Ventura)

This city, named for the Spanish Mission of San Buenaventura, has had a fairly steady rate of population growth over the last twenty years. The city added about 1,000 people per year in the 1970s, with growth of 2,000 to 3,000 people per year in later years (see Table 5-4) There are some anomalies in the growth pattern -- in the early 1980s the city annexed some populated land to its north.

The City of Santa Barbara is approximately 25 miles northwest of Ventura along Highway 101; downtown Los Angeles is 65 miles to the southeast. Ventura has been heavily influenced by growth of both the Los Angeles and Santa Barbara areas. Residential growth in the area created concerns about adequate water supply and increased traffic congestion on city streets. These problems led to the approval of the Ventura Growth Management Program (GMP) in 1979. This program relies on a build-out population forecast, this forecast is then used to determine what population growth should be in order to reach build-out sometime around 2010. The number of housing unit approvals allowed each year is then calculated using an estimate of 2.5 people per dwelling unit.

Under the GMP, allowable population growth in the city should be around 800 people per year. Residential growth in the city has generally exceeded this amount, meaning that future building permit approvals may be reduced. Much of the excess development is due to "grandfathered" projects rushed through right before the GMP was approved in 1979. In addition,

Table 5-4
City of San Buenaventura (Ventura) Population Trends

Year	Population	Rate
1970	57,964	--
1971	58,800	1.4%
1972	59,800	1.7%
1973	60,700	1.5%
1974	61,700	1.6%
1975	62,938	2.0%
1976	65,553	4.2%
1977	66,864	2.0%
1978	68,060	1.8%
1979	70,078	3.0%
1980	73,774	5.3%
1981	78,050	5.8%
1982	79,547	1.9%
1983	82,205	3.3%
1984	83,510	1.6%
1985	85,518	2.4%
1986	86,465	1.1%
1987	87,461	1.2%
1988	88,741	1.5%
1989	91,138	2.7%
1990	92,254	1.2%
1991	93,181	1.0%
1992	94,340	1.2%

Source California Department of Finance

many projects which have been approved remain unbuilt as developers wait for demand to increase and financing to improve. Knowing the approval process takes time (especially for large projects), some developers obtain building permits and complete environmental assessments during slow building periods, so that construction can begin as soon as economic conditions improve.

According to city planner Mark Stephens, the GMP was developed to ensure that growth in the city occurred in an orderly fashion and that adequate services would be available. In addition, it is intended to reduce development pressure on agricultural land by designating greenbelts in the area. Air quality was also a major issue; on a county-wide level, it was felt that limiting population growth would slow the increase in automobile use and emissions.

Until the national recession slowed development in Ventura, developers wished to build more units than the annual allowance under the GMP. This situation made for a very competitive approvals process -- over a two-year period the city received applications for around 2,000 dwelling units. The GMP limits building approvals to approximately 370 units per year

In addition to the GMP, an important factor restricting development in Ventura was the lack of an adequate water supply to meet increasing demand. Water shortages continue, and severe restrictions on the use of water are in place. The current supply would be used up entirely if all projects approved to date were actually built, so the city is looking for new sources of water. The city is considering a desalination plant, but will likely pay to import state water instead.

In response to the continuing water supply problem and the recession, the GMP has essentially been suspended since 1990, and the city will not approve any new permits until a new water supply is found. The city expects to have a new source of water within the next year or two.

Prior to the implementation of the growth management program in 1979, the City of Ventura based building permit approvals on the availability of services to the site. The types of services considered included water, sewer, drainage (this area has a high flood risk), parks, and circulation. The city would complete studies to determine deficiencies in services and estimate costs to expand services to new development. Development fees would be set to fund the service improvements, but could be reduced if the fees would make overall development costs too high.

The city encourages business and employment opportunities and tries to balance the amount of land zoned for employment-generating activities and housing. Nonresidential projects are not subject to the GMP. Ventura tends to compete heavily with the City of Oxnard for commercial development, such as retail, that serves the Oxnard/Ventura market. Regional planning in Ventura County ensures that new development occurs in already established cities where infrastructure is available; this city-centered development policy also helps the county conserve its agricultural land.

Mr. Stephens estimates that about half of the residents of Ventura work in the city and about half of the city's workers also reside there. In addition, the vast majority of those residents that work outside the city commute to jobs in nearby Oxnard, Port Hueneme or Camarillo. The Highway 101 freeway through the City of Ventura has never experienced traffic congestion, so the widening project had no significant effect on freeway travel times for city residents.

5.3.4.2 City of Oxnard

Residential growth in Oxnard has also been fairly steady, with a growth rate during the 1970s of approximately 2.5 per cent, dropping to 1.5 per cent in the 1980s. Oxnard has historically been a city with a large proportion of relatively low income households and a low skilled workforce. This situation has been changing somewhat with several newer developments with large homes and golf courses being constructed on the west side of town Families purchasing these higher-end homes tend to have jobs located in Ventura or Santa Barbara

Oxnard's housing supply currently exceeds its job base, but the city is trying to attract new business and increase its tax base. About one-third of Oxnard's labor force hold jobs outside the city; this proportion has remained fairly constant over the years.

Development has been very slow since the start of the recession; attracting new businesses is difficult Some older residents feel that the city has grown too quickly, and this feeling has prompted some proposals for growth control initiatives like those in Ventura, Camarillo, and Thousand Oaks. Oxnard wants to conserve agricultural land in the form of a greenbelt around the city, but allows conversion of agricultural land to urban uses within the city as long as the new land uses are consistent with the General Plan.

5.3.4.3 Development in Eastern Ventura County

Considering their proximity (within an hour's drive) to Los Angeles, it was anticipated that the cities of Ventura and Oxnard were likely to have developed as residential suburbs of Los Angeles. Discussions with planners from these two cities indicates that housing development there was mostly constructed for people working in Ventura or Santa Barbara counties, not Los Angeles.

The planners believe that growth in the cities of Simi Valley and Thousand Oaks is much more directly tied to regional growth in Los Angeles County and that these cities are developing primarily as commuter suburbs for people employed in Los Angeles It appears that growth of the Ventura/Oxnard economy generates sufficient demand for housing the western half of the county, and that Los Angeles commuters must compete for housing in Ventura and Oxnard with the local demand. The additional demand may mean that housing prices in Ventura and Oxnard are higher than what commuters from Los Angeles are willing or able to afford.

The cities of Simi Valley and Thousand Oaks both grew rapidly during the 1970s and 1980s as employment expansion occurred in Los Angeles. Annual population growth in the City of Thousand Oaks, for example, averaged 11.8 per cent over the period 1965-1975 (Thousand Oaks, 1990). Housing in these communities tends to attract mostly middle and upper-middle income families (Simi Valley, 1988). Freeway congestion is a concern in the Simi Valley and Thousand Oaks areas (Simi Valley, 1988, Thousand Oaks, 1990), but these communities continue to approve new development and support freeway widening projects to increase capacity as growth continues.

5.3.4.4 Conclusions -- Los Angeles Area

Highway 101 operates with little or no congestion in the City of Ventura, but there is noticeable congestion on the freeway in and east of Oxnard This freeway and its connections to the Los Angeles metropolitan area to the south and to Santa Barbara to the north were important to growth in the Ventura/Oxnard area, but few residents of these cities currently commute to jobs in Los Angeles.

In general, the widening of Highway 101 seems to have reduced travel times only for those commuters travelling from the bedroom suburbs in the eastern portion of Ventura County to jobs in Los Angeles Simi Valley and Thousand Oaks recognize the importance of the freeways that link their residential developments with Los Angeles employment. It appears that they expect highway improvements as necessary to accommodate continued growth in commuter traffic.

5.3.5 Case Study 4: San Diego Area -- I-15

The San Diego project corridor is I-15 between San Diego and the northern suburb of Escondido (the Escondido Freeway), shown in Figure 5-4. The 10-mile section was widened from 4 to 8 lanes, with funding committed in 1979 and construction completed in 1982. In addition, the 8-lane Escondido Bypass was programmed in 1972 and completed in 1977. I-15 was also extended north to the Riverside-San Bernadino area in the 1980s.

5.3.5.1 City of Escondido

As shown in Table 5-5. Escondido experienced rapid growth during the 1970s and 1980s. Much of this new development was housing, but some new retail (including a regional shopping mall) was added during this period. Little expansion has occurred in office or industrial development in recent years. Many long-term residents became unhappy with the increased traffic congestion on city streets that resulted from the growth, and concerned about freeway congestion as well. The city now supports managed or slow growth as a way of reducing undesirable impacts. Escondido's residents have been attracted to the city because of the affordable homes and the attractive, "small-town" feel of the community, as well as its proximity to employment in San Diego.

Several growth management ordinances have been adopted by the city to limit residential development. Many developers seeking to avoid the competitive bidding process for permit approvals have negotiated development agreements with the city. Some of these agreements give vesting rights to the developer for ten to fifteen years; developers are then able to delay construction of the projects until market conditions are favorable.

The city updated its general plan in 1990, and this process resulted in downzoning of a significant portion of the planning area. The build-out capacity of the city was cut in half from 300,000 to about 155,000. The city's 1992 population is about 110,000, and the city expects to

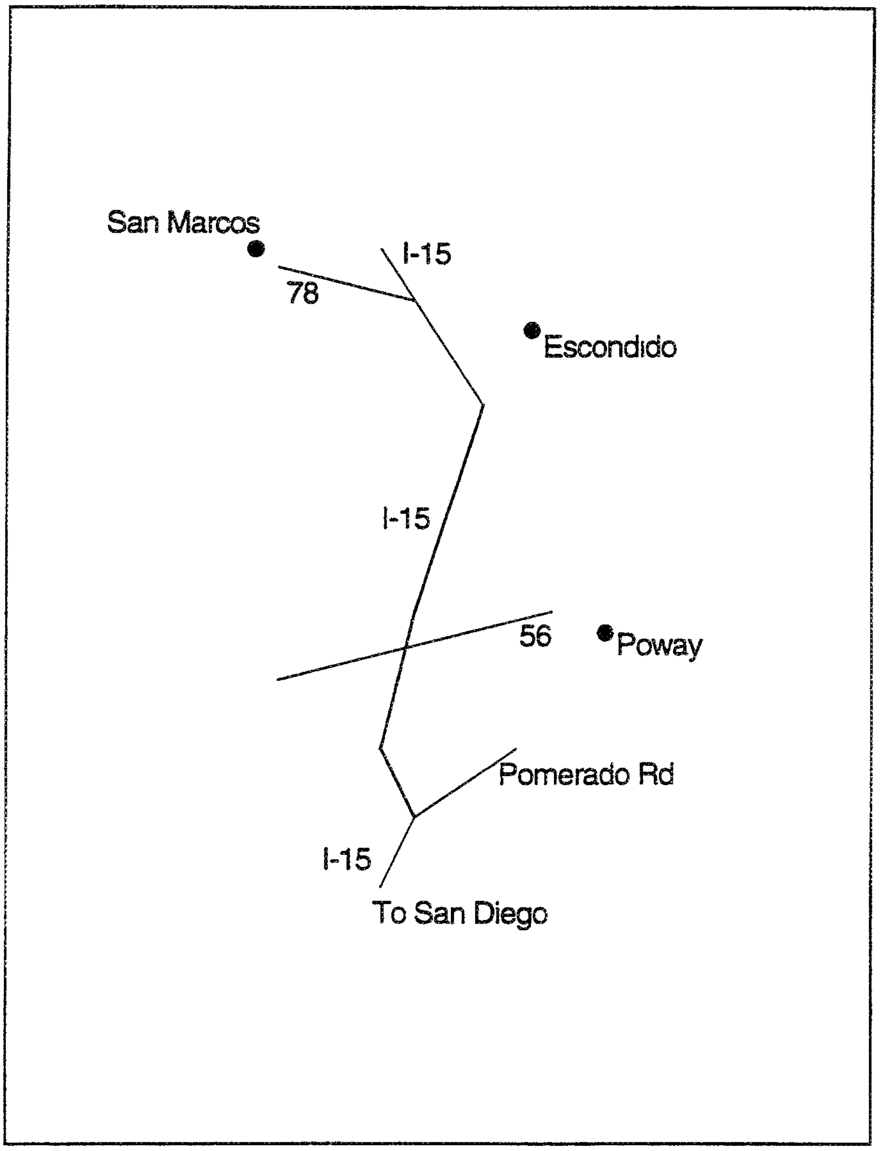

Figure 5-4
Case Study 4: I-15, San Diego Area

Table 5-5.
City of Escondido Population Trends

Year	Population
1960	16,377
1970	36,792
1980	64,355
1989	99,000

Source. San Diego Association of Governments

Table 5-6.
City of San Marcos Population Trends

Year	Population	Rate
1976	10,400	---
1977	12,100	16.3%
1978	14,053	16.1%
1979	14,600	3.9%
1980	17,479	19.7%
1981	17,832	2.0%
1982	18,185	2.0%
1983	18,522	1.9%
1984	19,050	2.9%
1985	19,873	4.3%
1986	20,900	5.2%
1987	23,376	11.8%
1988	26,300	12.5%

Source: San Diego Association of Governments reach build-out around 2010.

Another major policy element of the new general plan involved the adoption of a set of ten "quality of life" standards, which are designed to ensure that "...adequate schools, infrastructure, services and open space are provided in a timely manner (City of Escondido,1990)." Traffic and transportation is one of the standards considered important to quality of life in the city According to the general plan, the city expects traffic congestion on city streets during peak hours, especially at freeway interchanges and in the downtown area.

According to city planner Barbara Redlitz, Escondido is a major exporter of workers to jobs in San Diego, so anticipated new housing development in Escondido is expected to increase travel demand along I-15 The freeway operates at an acceptable level of service near Escondido but congestion increases as one approaches San Diego Route 78, which connects Escondido with the coast, is heavily congested during the peak hours. In spite of projected future traffic congestion on these facilities, the city does not discourage or deny projects based on trips generated on the freeways.

Currently, a big issue influencing growth in Escondido concerns the habitat of the California gnatcatcher. The U.S Fish and Wildlife Service has decided to wait up to six months to determine whether it will declare this bird an endangered species (S.F Chronicle,1992). Much of the undeveloped land in Escondido's sphere of influence is covered with vegetation that supports the gnatcatcher's habitat Listing of the bird as an endangered species could potentially result in restrictions on development in areas slated for future housing subdivisions.

5.3.5.2 City of San Marcos

The City of San Marcos encourages development to concentrate near the already urbanized area to take advantage of existing service infrastructure. Many areas in San Marcos are also the habitat of the California gnatcatcher, and the Fish and Wildlife Service's determination could impact where future development occurs and how much is allowed. Population growth in San Marcos has varied widely over the past several years, as seen in Table 5-6. Development occurred rapidly in the city in the late 1970s but slowed to around 2 per cent in the early 1980s. The growth rate rose again in the mid-1980s.

Housing development continues to be the fastest-growing sector in San Marcos; home buyers are attracted to the rural atmosphere of the area and the low home prices. Much of the housing is being constructed as large subdivisions by out-of-town developers. According to city planner David Acuff, many newer, smaller businesses (or "infant industries") have been attracted to San Marcos in recent years by the availability of land for expansion at low rents. The city continues to seek industries to increase the tax base and provide jobs for local residents.

Development approval is not denied based on traffic levels on either city streets or the freeway, but most developers pay fees to fund service improvements. Developers also have the option of completing the infrastructure upgrades themselves In some cases, requirements for road improvements are tied to actual traffic impacts. For example, one developer was required to build a basic arterial to serve his subdivision Future traffic counts will determine if the developer needs to widen the road.

5.3.5.3 Conclusions -- San Diego Area

The cities of Escondido and San Marcos, like the rest of the San Diego region, have experienced significant population growth over the last two decades. Cities in north San Diego County have grown because they have been able to offer an attractive rural environment and low housing priced for commuters. Traffic levels along I-15 have steadily increased over the years, but planners with the cities of Escondido and San Marcos indicated that the widening of this facility did not noticeably affect the level of service.

Demand by commuters of homes in these cities appears to remain strong; planners expect to approve new development even as traffic congestion increases. It does not appear that planners would have expected different levels of growth in North San Diego County if the I-15 widening had not occurred.

5.4 Highway Capacity Expansion and Land Development: Developer Perspectives

5.4.1 Introduction

This section will discuss the results of a survey of real estate developers who built projects in Pleasanton (Case Study 1) during the study period 1970-1990. The type and density of development that occurs on a particular piece of land will depend on many factors; this part of the research looks at freeway expansion as one factor influencing an area's development. As discussed in the introduction, one would expect, based on economic theory, that increasing freeway capacity to a site would increase the attractiveness of the site to developers and would inflate the land price.

In order to make a profit on developments using more expensive land, one could expect the land to be used more intensively (Echenique,1980). This relationship between land price and density is evident in the high rise office buildings located on expensive, centrally-located sites. It is possible that an increase in land value would encourage builders to increase the density of their developments or construct more expensive housing with a higher profit margin Generally, however, developers included in this survey felt that their development decisions (i e. size, scale, and price range) were unrelated to the I-580 freeway expansion

The expansion project could have indirectly inflated the land values (without the developers' knowledge), meaning that less overall development would have occurred in the absence of the widening project. The potential for freeway expansion to indirectly influence development decisions could help explain the difference in results of this survey and the findings (related in chapter 4) of a positive correlation between freeway capacity increases and corridor shares of permit activity. It is also possible that the developers did value the freeway improvement project but did not acknowledge this, out of concern for the political ramifications of doing so.

5.4.2 The Survey Process

The projects selected for study are randomly chosen from a list of projects obtained from the planning departments files Telephone conversations were conducted with developers of small and large residential projects, and with developers of two major commercial/office/industrial (C/O/I) projects in north Pleasanton along I-580. Background information on a third C/O/I project, the massive Hacienda Business Park, was obtained from a 1989 study of Pleasanton's planning process (LeGates and Pellerin) and a 1988 study comparing Bay Area employment centers produced for Hacienda (Keyser Marston)

A copy of the survey is shown in Figure 5-5. The questionnaire covered the planning process for the specific development project selected as well as general information based on the developers experience with other projects. Through the survey we attempted to discern the

(1) Explain briefly the planning process for the ______ project -if possible, give dates of critical planning decisions.

(2) What types of features would make a site particularly attractive to you?

(3) How does access to a freeway or highway factor into your feasibility analysis of a site?

(4) Would a high level of traffic congestion (i.e. stop-and-go traffic) on nearby freeways and major arterials discourage you from considering a particular site for development? Why or why not? Do you know of any projects that were denied permits because of highway congestion?

(5) Would a planned expansion of the congested facilities influence your decision? Have you ever advocated for a particular roadway project?

(6) Evaluate the State Route 4 area (Pittsburg/Antioch) as an alternative to the I-580/I-680 area for development purposes.

(7) Were you aware of the I-580 expansion during planning for your project?

(8) Residential developments: Who are the homes being built for - where will they work?

Figure 5-5.
Developer Survey

importance of various aspects of the transportation system on development decisions, including freeway access, the level of traffic congestion on nearby freeways, and planned transportation improvements.

A map of the development projects selected is shown in Figure 5-6. The next section contains descriptions of the individual projects Following these descriptions are the developers' more general comments on planning for residential and nonresidential projects. It should be noted that these opinions are to a large extent based on developers' overall experience in the field, rather than the specific projects in Pleasanton that were reviewed.

The inherent differences between residential and nonresidential land uses warrant separate treatment of projects in these categories. In addition, it appears that major retail developments, such as shopping centers, value the transportation system differently than other C/O/I land uses, and such projects will therefore be discussed in a separate section

5.4.3 Descriptions of Projects/Developers Surveyed

5.4.3.1 Via Siena/Stoneridge Drive; Bren Development Company

This residential project, currently under construction, has 112 single family homes on 13.7 acres. It is located in northeast Pleasanton off Stoneridge Drive and Santa Rita Road. The project was approved in 1990, well after the first phase (near Pleasanton) of the I-580 highway expansion was completed.

The area is fairly flat and was zoned for high density residential The city wanted high density, low income housing built on the site, but the developer determined that it would make a better profit by building single family detached homes. The price of the land was the most important consideration in choosing the site. While the site is not adjacent to the freeway, it has reasonable access to I-680 via Santa Rita Road

5.4.3.2 Country Fair Downs; Ponderosa Homes Development Company

This development consists of 180 single family homes on 38.2 acres in central Pleasanton along I-680. This project, approved 1984, was an addition to existing development in the same area. The developer chose this site because of the price of the land. They considered the freeway access for this site, but that factor was no more important than any other. The developer was

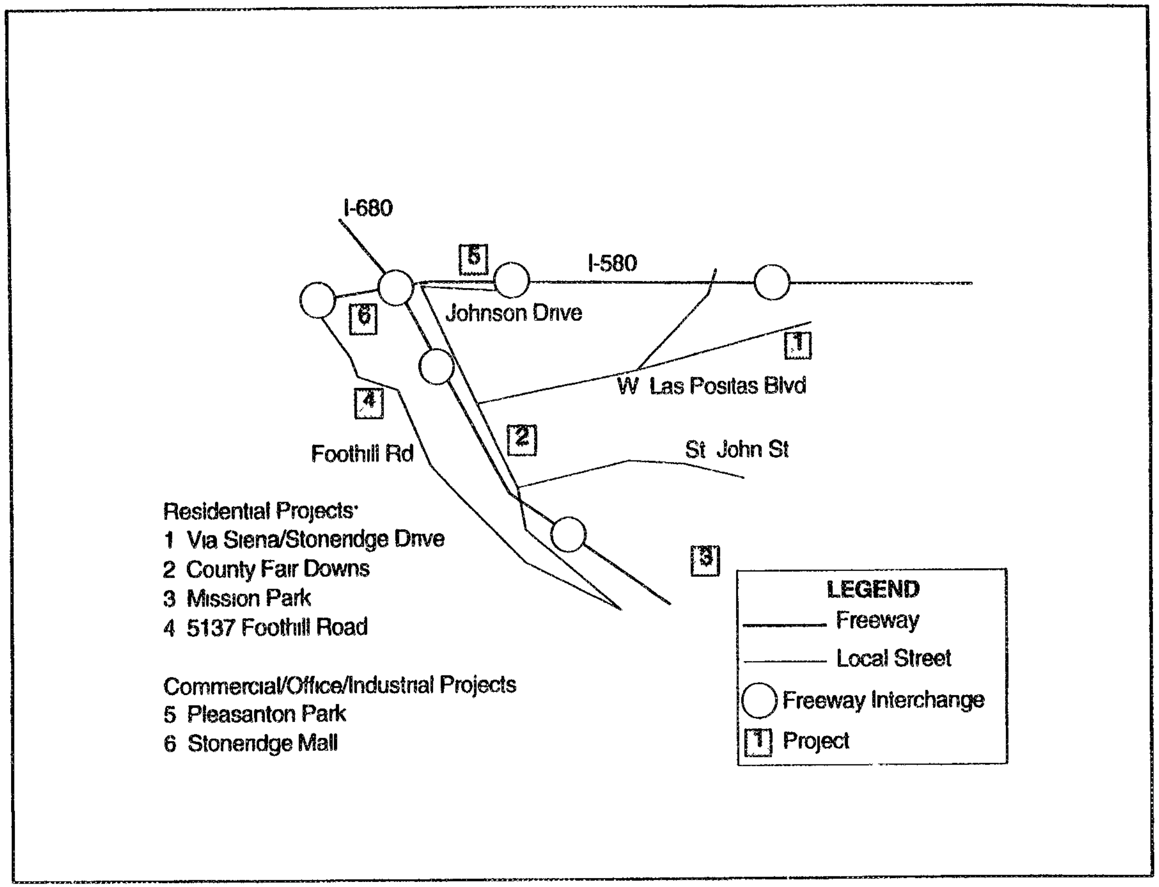

Figure 5-6
Pleasanton Development Projects Selected

aware of the I-580 highway expansion; the second phase of the widening was in process by the time they began planning for this project.

5.4.3.3 Mission Park; Beratlis Development Company

This small residential project of 27 homes in located in the southern portion of Pleasanton A 30-day option was taken out on the property while the developer performed an economic study. During this study, the developer analyzed the land costs, city fees, and costs of development (including building costs and infrastructure) Determining that the homes could be built at a profit and in a price range appropriate to the neighborhood, the developer proceeded with the project. This developer was aware of the I-580 expansion, but believes that the widening did not affect his project because most of the residents purchasing the homes work in the Silicon Valley and commute along I-680, not I-580.

5.4.3.4 5137 Foothill Road; Pancal Development Company

This project was purchased from another developer in 1990, when it was about halfway through the planning stage, with the layout of the tract and the design of the homes completed. The development plans were filed with the city by the original developer in 1988 These homes are in the middle and upper price range.

This developer generally does infill projects, he said he does not build in remote areas, and that he has not built any projects in the Highway 4 area -- another east-west corridor about 30 miles north of I-580 -- because the homes built there are often starter homes in a lower price range than what he typically builds. His company generally prefers locations near major highways, whether they are congested or not Some of the projects this developer is currently working on are in Dublin (near I-580/I-680), San Jose, Sunnyvale, Saratoga and Cupertino (near I-280).

Freeway access was important for this project; both I-580 and I-680 are easily accessed from the development. The homes were built for more affluent people who are able to pay more to locate in a high quality neighborhood near work and shopping destinations. The developer believes that the I-580 widening was not important to this project because the residents commute north along I-680 to jobs in Walnut Creek and San Ramon or south to Silicon Valley.

5.4.3.5 Pleasanton Park; Reynolds and Brown Development Company

This project is a commercial/industrial business park located along I-680 near the I-580/I-680 interchange. The project site is approximately 56 acres and contains office, research and development, warehouse. light industrial, and commercial uses. The developer split the property into four parcels which were developed in phases, plans for these parcels were filed with the city in 1980, 1982, 1986 and 1989. The splitting of the property involved the realignment and improvement of Johnson Road (a frontage road along I-680), and improvements to the Hopyard Road interchange at I-680. Phases 1 and 2 have mainly research and development, warehouse, and light industrial uses. Phase 3 was planned for some office space, but due to a glut of office space on the market at the time (late 1980s), this was changed to retail Phase 4, which is still vacant, is also planned for retail uses.

This site was chosen because of its location along the freeway. Accessibility was very important for the retail, industrial, and warehouse development planned for the site. The developer conducted a feasibility study of this site before purchasing it in 1980, including looking at the amount of daily traffic using the freeway in front of the site According to the developer, a relatively high level of traffic flow along the freeway was desired to provide exposure for the retail uses They also examined demographic characteristics of the area, including population, employment, and income levels, to determine if the site would be successful for retail businesses.

While traffic congestion on I-580 did not hinder people's ability to get to the site, the developer did contribute money to the North Pleasanton Improvement District to pay for the roadway improvements to Johnson Road and the Hopyard interchange. The company only builds projects on sites along major freeways because their commercial/industrial projects need good accessibility and visibility. Current projects are in Fairfield, along I-80 in Solano County, and in Tracy, along I-580 in San Joaquin County.

5.4.3.6 Stoneridge Mall; Taubman Development Company

The developer started planning for the Stoneridge Mall in 1972, and the mall opened in 1980. The site was zoned for a regional shopping mall in 1972. At that time there was another developer that wanted his site zoned for a shopping center. Both companies made presentations to the city. Taubman's site was selected, among other reasons, because of its superior access to and visibility from the two freeways.

Two factors important to the development process were the sewer capacity limitations of the city and transportation improvements, including the Stoneridge Boulevard overpass at I-680, where a full interchange was eventually built. The lack of sewer capacity influenced the shopping center in two ways. The direct impact was that the Taubman Company did not have assurance of sewer service for its site. This problem was overcome when a lawsuit made by another developer against the City of Pleasanton was settled, and the mall site was guaranteed sufficient service by the city in 1978

The developer was concerned that the population density in the Tri-Valley trade area was not sufficient at the start of planning -- a larger population base was needed in order to create sufficient demand for the mall department stores. The sewer capacity limitation was seen as a threat to the success of the mall because it would hinder population growth in the area. The developer, however, assumed that the sewer capacity would be increased by the city sometime soon, and seeing the potential for growth in the market area, decided to go ahead with the project. The developer's assumption proved correct: the cities of Livermore and Pleasanton passed a bond measure and received federal assistance to finance construction of a pipeline to transport treated sewage from the valley to the Bay. The additional sewage capacity enabled residential development to restart in 1976.

There were several elements that made this site attractive for a regional shopping mall. The flat topography of the site made it conducive for development of a shopping center, and the city was receptive to rezoning the site for commercial use In addition, the location at the junction of the two major freeways gave the site good exposure and visibility. The developer also felt that Pleasanton was a "friendly" city in which to do business. While the site only had direct access to I-580 at the time the project was being planned, the developer believed that local improvements could be made to connect the site with I-680 as well.

Direct access to both freeways was considered critical to the project so that it would be convenient for people traveling on the freeways to get to the mall. Access to I-580 was along Foothill Road, which the developer planned to widen to adequately handle the additional traffic. The developer also wanted an interchange at I-680, but was concerned that the expanded approval process for an new interchange on a federal interstate would complicate the approval process for the mall itself.

The developer was concerned that the EPA would stymie the project. so plans for a direct connection to I-680 were dropped, in order to avoid environmental assessment at the federal level. Instead, the developer chose to only build an overcrossing, which was crucial to providing adequate access to the site for Pleasanton residents Caltrans prepared an environmental impact statement for the overcrossing, which was approved and built. A freeway interchange at Stoneridge Drive was later added through funding by the North Pleasanton Improvement District.

The developer of the Stoneridge Mall was aware and in favor of the I-580 widening project. While the mall would still have been constructed even without the widening, the improvement was welcomed The developer was in favor of the highway expansion because the reduced congestion and faster travel times would make the trip to Stoneridge more convenient for customers from Castro Valley and Hayward, thereby increasing the mall's effective market area Construction on the mall began in 1978, by which time the widening project was already underway.

5.4.4 General Comments on Developer Site Analysis

5.4.4.1 Residential Developments

The key concern of residential developers when evaluating a site for construction of homes is whether the homes will sell quickly at a profit for the developer. This concern motivates their consideration of what type of housing would be suitable for a particular site as well as what sites are appropriate for development. The developers interviewed for this study stress that they avoid very remote areas with poor regional accessibility Noise and vibration associated with freeway traffic make sites directly along major freeways relatively unsuited for residential uses, but locations a short distance from freeway interchanges are quite desirable.

The proximity to freeways is not, however, considered a very important factor for many projects. Developments involving large numbers of homes which are expected to generate a lot of traffic need to have better access, making a location near a freeway more desirable. In addition, developments of homes in the higher price range may be located close to freeway access points because the high degree of accessibility would attract affluent home buyers who value their time highly and are able to pay more to live close to attractions, such as employment centers and shopping areas. Even for the affluent, however, the quality of the neighborhood would still be considered more important than freeway access (Ho, 1992).

Due to the lack of available land in the tight Bay Area housing market, residential developers cannot afford to be picky about special amenities, such as direct freeway access or topographic features like creeks and hills. The most important factors considered in initial site selection are the price and size of the property, and the nearby land uses In addition, developers will not actually purchase a piece of property until they are assured that they can build on it A developer might place an option on a piece of property that is reasonably priced and then conduct an analysis of various factors which would help him/her determine if a profitable project can be built.

The factors considered in this analysis are generally related to development costs or to government regulation of land, usually in the form of zoning. The developer determines what type of use the property is zoned for, and calculates any development fees imposed by the city as well as costs of infrastructure improvements (on and off-site). Outlining all of these types of costs allows the developer to determine the general price range at which the homes need to be sold in order to make a profit. If the project appears financially feasible, the developer will purchases the property and applies for a building permit.

The residential developers interviewed said that congestion on nearby freeways would not affect site feasibility analysis, and would not diminish the attractiveness of a site. According to one developer, residents of urban areas tend to anticipate some congestion on freeways during peak hours and expect this to increase their travel time Following this line of reasoning, traffic congestion on a freeway would not tend to discourage people from purchasing a home in that corridor, if the homes are reasonably priced. A lack of congestion on a freeway is unlikely to attract homebuyers to the area unless the homes pass the other, more critical, tests of price, size, and quality.

Developers of small projects, in particular, are unlikely to conduct a detailed evaluation of a site's amenities, including access to freeways. Because the budgets for small projects do not generally include resources to evaluate the level of access to freeways and other major transportation facilities, these developers would clearly not take the next step of considering the level of *congestion* on these facilities. In addition, small projects are not expected to produce a significant level of new traffic and often do not require environmental impact assessment.

There is some concern on the part of developers that congestion on local transportation facilities could hinder approval of a projects building permit application The developers were unable, however, to relate any specific instances where a permit was denied on the basis of excessive traffic impacts on already congested local roadways. They generally believe that agreements could be reached with the city to mitigate traffic impacts through spot improvements adjacent to the site. These types of mitigation measures, while they can be quite expensive, are generally of a small scale and include addition of lanes to access roads or freeway ramps, signalization improvements, and so forth.

Development of a project in a congested corridor may result in approval delays and additional costs, including the cost of traffic impact assessment and actual costs for the improvements on freeways and main arterial at the freeway interchanges. The increasing costs may make a potential project site relatively less attractive for development, but the final decision depends on the overall costs.

5.4.4.2 Major Retail Developments

Retail businesses look for new opportunities in areas of significant population that are underserved by existing retail services. Around the country, the development of large shopping centers in the suburbs followed soon after those areas experienced population growth. Pleasanton's major regional shopping center, Stoneridge Mall, opened in 1980 to serve the retail needs of the growing Tri-Valley population.

Major shopping centers such as Stoneridge rely on visibility and accessibility to large numbers of people for their success, making a location immediately adjacent to major freeways of primary importance. Average daily flow of vehicles past a retail site is considered a critical measure of visibility and exposure, so a heavy traffic flow on a freeway could be perceived as positive. A site at the junction of two freeways with immediate access to them, such as the Pleasanton location of the Stoneridge Mall, is the ideal type of site for shopping center developers.

As with developers of other types of large projects, retail developers would consider funding spot improvements to both city streets and freeways to enhance access to their developments. Developments expected to generate a heavy amount of traffic, such as a shopping center, are often required to implement these types of measures to mitigate the adverse traffic impacts, but only in their immediate vicinity.

5.4.4.3 Other Commercial/Office/Industrial Developments

Developers of commercial properties generally consider land price, demand by businesses for new office space, and vacancy rates of existing developments as very important to their feasibility analysis. The San Francisco Bay Area's strong economic growth created demand for significant amounts of new office space Developers planned new projects to accommodate the need for space for high-growth companies, often in such fields as financial services and high-technology.

The forms of office/commercial development have changed significantly over the past few decades, with suburban office parks becoming increasingly common. While traditional downtown areas such as San Francisco and Oakland continue to add to their stock of office space, much of the region's office growth over the last ten years occurred in suburban communities such as Pleasanton and Sunnyvale. These outlying areas are seen as having several advantages over inner city office complexes, particularly for newer, smaller businesses requiring low rent office space with room available for expansion According to a study completed for the Hacienda Business Park, some of the merits of the Tri-Valley area that have attracted employers to the development include: "rapid population growth, excellent housing availability, good quality schools, untapped labor supply, improving freeway system,[2] and low occupancy costs (Keyser Marston; p. 37)."

Employers have been attracted to the Tri-Valley area in part because of growth of the local labor force; many of the new jobs have been taken by local residents or by people who moved to the area after starting their job. This indicates that few employees of Pleasanton firms need to use the I-580 freeway for their commute In 1990, only 16 per cent of the Pleasanton workforce commuted along I-580 through the Dublin Canyon from San Francisco and the East Bay. Approximately 25-27 per cent of Pleasanton's workers resided in the Pleasanton area, and

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[2] Improvements planned or under construction at this time were mainly to the I-680 freeway and the I-680/Route 24 interchange The widening of I-580 had already been completed

another 30 per cent lived in the nearby communities of Livermore, Dublin and San Ramon, which are accessible by the arterial street system in addition to the freeways. Much of the remainder commuted to Pleasanton along I-680 from the north (Concord, Pittsburg) or from the South Bay cities such as San Jose and Sunnyvale (1991 Growth Management Report: p. 89).

As with residential properties, the importance of freeway access for office and commercial projects depends in part on the size of the development and the level of traffic that will be generated by the project. The Hacienda Business Park, for example, is expected to have approximately 40 thousand employees at build-out; the site at the junction of the I-580 and I-680 freeways was chosen for the park to allow easy freeway access to the freeways and minimize traffic impacts on city streets.

Proximity to the freeways is important to industrial firms because their operations require them to be very accessible Manufacturing and warehouse/distribution facilities in particular need adequate freeway accessibility to accommodate truck deliveries and distribution activities. In addition to freeway access, however, these types of large-scale operations require large parcels of land at relatively low prices in order to be profitable However, as long as a suitable site could be found near a freeway, industrial firms would make their decision to locate there independent of any traffic congestion on the facility, according to developer Kelly Reichenberg.

5.4.5 Developer Perspectives -- Conclusions

Overall, it appears that the existence of the two freeways and the access that these facilities provided to the inner Bay Area and South Bay and to growing residential suburbs in the San Joaquin Valley were very important to Pleasanton's population growth and the expansion of C/O/I activities there. While freeway service level was mentioned as somewhat of a concern to developers, most notably for the shopping center, the availability and low price of land in the area was clearly the most important consideration.

While an increase in capacity of transportation facilities may have been perceived as a bonus to nearby developments, the ability to satisfy regional demand for affordable housing and competitive-rent C/O/I space appears to have been the most dominant force shaping growth and development in Pleasanton during the last thirty years.

5.5 Conclusions

This case study analysis examines growth and development trends in four corridors in which existing highways have been expanded and attempts to relate these trends to the capacity increase. The basic premise has been that increased growth leads to a greater number of trips, increasing traffic congestion If it is found that an improvement of a freeway facility attracts new growth to the corridor, the eventual result would increased traffic on transportation facilities, and therefore higher levels of congestion and air pollution.

Research on the growth and development histories of communities in the improved corridors indicates that the existence of the freeway system was very important to development in these communities. The freeways provide critical access between the corridor communities and the remainder of the region. In the case of Pleasanton, for example, the professionals agreed that the city's location at the crossroads of the two major freeways, I-580 and I-680, was crucial to the growth of its residential areas and its ability to attract new businesses and employment. It appears that the strong growth of the Bay Area economy and the build-out of inner parts of the region produced excess demand for affordable land for residential and nonresidential uses

While the existence of the facility itself is critical, the link between the expansion of a highway and growth and development in the corridor it serves appears to be much weaker, or at least less direct. Generally, communities along the improved corridor were able to attract the excess demand for housing because these outlying areas could offer low land prices and access via the freeways to the region's job markets. Land cost and an attractive rural environment appear to be the overriding factors motivating housing development in all four case study regions Outlying areas with lots of undeveloped land generally grew faster than more developed communities These types of factors appear to be more directly relevant to the project decisions of real estate developers than the level of highway congestion in the area. While the expansion of I-580 is seen as a bonus to developers in the area, all indicate that their projects would still have been constructed in the absence of the freeway improvement.

It is possible that the development market did place value on the freeway expansion, but that this influence is not easily recognized. Improved capacity along the freeways serving the developments could have indirectly increased the value of the land, potentially leading to different levels or types of development than would have occurred without the freeway improvement. Shorter travel times (due to reduced congestion) could also be attractive to residents using the freeways to commute to work, allowing them to obtain better housing by commuting a greater distance. Also, since development decisions are highly cost-sensitive, any effect of congestion on development cost, such as a requirement that the developer pay for transportation improvements, could influence these decisions. These effects are all indirect in the sense that the road capacity variable influences another variable that in turn affects the development decision. This could explain why the impacts of capacity increases are not readily apparent in the case study analysis.

Discussions with local planners in the four regions also expressed an apparent lack of appreciation for the cumulative traffic generation impacts of local development on the regional transportation system. Most of the communities involved in this study indicated that they do specifically consider regional traffic impacts when deciding whether to approve or deny development projects. This policy could result in unchecked increases in traffic congestion on regional freeways, whether they are expanded or not. Alternatively, it may shift responsibility to developers, real estate purchasers, tenants, and others to respond to congested road conditions in their development, purchasing, and location decisions The case studies presented in this chapter suggest that such responses, if they occur, are not recognized as such by the above decisionmakers Perhaps this shows that markets for suburban development are guided by a truly "invisible" hand when it comes to transportaton, and perhaps it shows a failure of such markets in this regard.

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Chapter 6:

Area-Wide Impacts

6.1 Introduction

This chapter studies relationships between highway capacity and traffic on an area level. Highway expansions can affect traffic throughout a wide area. It is difficult for before-and-after studies based on specific projects to detect impacts outside the immediate vicinity of the improved segment. Although regional transportation models can do this, they are data and computationally intensive, difficult to validate, and yield far more detailed results than what are required for the present purpose. Most importantly, these models often exclude certain potentially important impacts, such as land use change and trip generation

Area-wide models are macroscopic in nature. They establish direct statistical relationships between traffic and roadway supply variables defined at the regional level. Thus, they can be used to estimate the growth of traffic in a region due to roadway expansion. While such estimates may not prove accurate for specific projects, they are invaluable in assessing the impact of road programs from a macroscopic, regional perspective.

Previous area-wide studies have relied on cross-sectional analyses. In this analysis, we use panel data. In other words, our data set consists of multiple observations, extending over a period of 18 years, for a set of urban areas. The use of panel data in this analysis provides three major benefits for model estimation: (1) discrimination between interregional and intraregional differences, (2) elimination of estimation bias due to omitted variables (variables which affect traffic, but are not included in our model), and (3) reduction of data multicollinearity, which reduces the accuracy of coefficient estimates.

In performing this study, we encounter a significant data limitation. While vehicle-miles traveled (VMT) data for state highways are available over a sufficient period to include significant temporal variation in roadway supply (measured in lane-miles), data for total VMT (including local roads) are available only for a considerably shorter span of years. Consequently, the main focus of our study is on how the supply of <u>state</u> highways affects traffic on <u>state</u> highways. This analysis does not, however, reveal whether the effects derive primarily from

Table 6-1.
California CMSAs and MSAs

NAME	DESIGNATION
Los Angeles-Anaheim-Riverside	CMSA
San Francisco-Oakland-San Jose	CMSA
Bakersfield	MSA
Chico	MSA
Fresno	MSA
Merced	MSA
Modesto	MSA
Redding	MSA
Sacramento	MSA
Salinas-Seaside-Monterey	MSA
San Diego	MSA
Sanra Barbara-Santa Maria-Lompoc	MSA
Stockton	MSA
Visalia-Tulare-Porterville	MSA
Yuba City	MSA

generation of "new traffic" or merely reflect reallocation of traffic between state and non-state highways. To address this issue, we also analyze more limited total VMT data, and tentatively conclude that the state highway VMT relationships primarily reflect traffic generation

A second potential problem with this study involves the direction of causality. Our analysis assumes that road supply is the cause and traffic the effect, whereas in fact, traffic levels affect road supply as well. While we concede that the causality is bidirectional, we do not believe that this substantially affects our results. State and regional planning processes are subject to imperfect information, lumpiness of investment, fluctuations in costs and revenues, politically motivated allocation formulas, and other "exogenous" factors that significantly loosen the coupling between road supply and road traffic. This allows us to treat roadway supply as an exogenous variable, so long as we control for other factors, such as population, population density, and income, which affect both vehicle traffic and road supply

The analysis will be presented in three parts. First, we focus on bivariate correlation and graphical analyses intended to give an intuitive sense of the relationships contained in the data. Next, we perform multiple regression analysis in order to isolate the impacts of road supply and other variables on VMT in a more precise and rigorous way. Next, we shift from the state highway VMT data considered in the first two analyses to the total VMT data, again applying multiple regression analysis Before turning to these analyses, Section 6.2 gives a brief description of data. Sections 6.3 and 6.4 analyze state highway VMT data, using bivariate and multiple regression approaches, respectively. Section 6.5 discusses the multiple regression analysis of total VMT data. Implications of our results are presented in Section 6.6, while Section 6.7 offers conclusions.

6.2 Data Description

6.2.1 Sources

For each of the thirty-two urban counties in California, annual data for vehicle miles traveled on state highways (VMT), population (POP), real personal income per capita (PIN), gasoline price (GPRICE), population density (DENSITY), and lane-miles of state highways (LMILE) were collected By urban counties, we mean counties that are within Metropolitan Statistical Areas (MSAs), as defined by the U.S Office of Management and Budget. Table 6-1 lists California MSAs. The time duration of the data is from 1973 to 1990, except for VMT on non-state highways which was available only for 1980, 1982, 1986, 1988, and 1989.

The data are obtained from various sources. The data for state highway VMT are provided by Caltrans. The California Statistical Abstract is the source of total VMT data Population, personal income and land areas are available from the California Statistical Abstract, County and City Data Book [United States] Consolidated File, County Data 1947-1977, and County Statistics File 2 (CO-STAT 2): [United States] Gasoline price is obtained from State Energy Price and Expenditure Report by the Energy Information Administration. Data for lane-miles are generated from Caltrans' Traffic Accident Surveillance and Analysis System (TASAS) data base, as elaborated in the next section

6.2.2 Development of Lane-Mile Data

There are three ways to obtain the county lane-mile data. First, these data are available directly from Caltrans. Second, the data can be calculated from segment data contained in the Caltrans Current Highway File, part of the TASAS data base maintained by Caltrans. Finally from Current Highway File and Prior Highway File, also part of TASAS, can be employed. This latter method reflects changes to the highway stock resulting from deletions of reconstructed, realigned, or abandoned segments, as well as additions of segments currently in use. The lane-mile data available directly from Caltrans covered only from 1977 to 1990, while data from TASAS covered 1973 to 1990.

In order to decide which lane-mile data to use, we compared the three data sets obtained in various ways, as shown in Figures 6-1, 6-2, and 6-3. All three figures show that the Caltrans lane-miles (those obtained from Caltrans directly), and the TASAS lane-miles (those obtained using both the Current and Prior Highway Files), are generally consistent, while the Current lane-miles (generated from Current Highway File alone) are considerably lower than the others.[1]

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[1] Lane-miles based on the Current Highway File is lower because it measures the lane-miles currently in place (as of 1991) that were in place in a given year This file does not contain lane-miles not currently in place that were in place in a prior year For example, if a section of road had been straightened in 1978, the Current Highway File would not contain the prior, unimproved section.

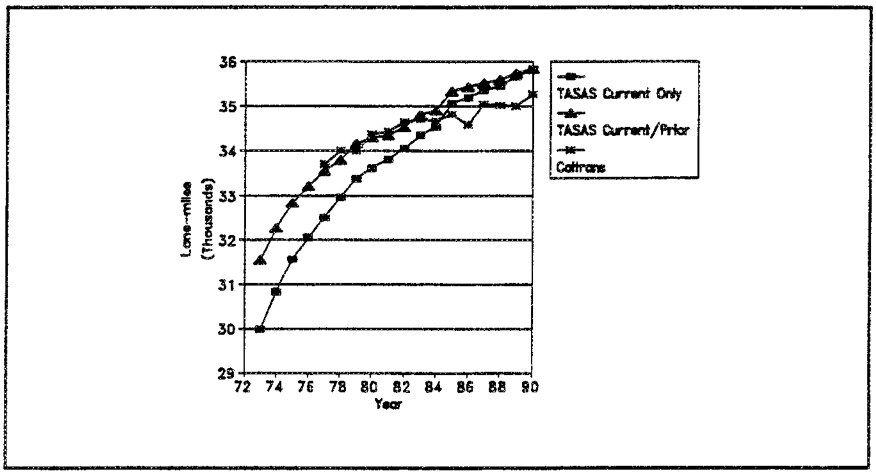

Figure 6-1 Alternative Lane-mile Estimates, State Totals

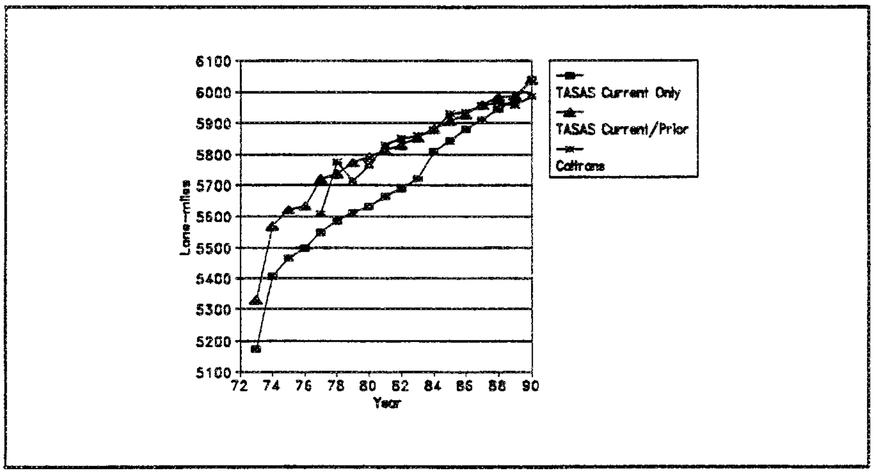

Figure 6-2. Alternative Lane-mile Estimates, Bay Area

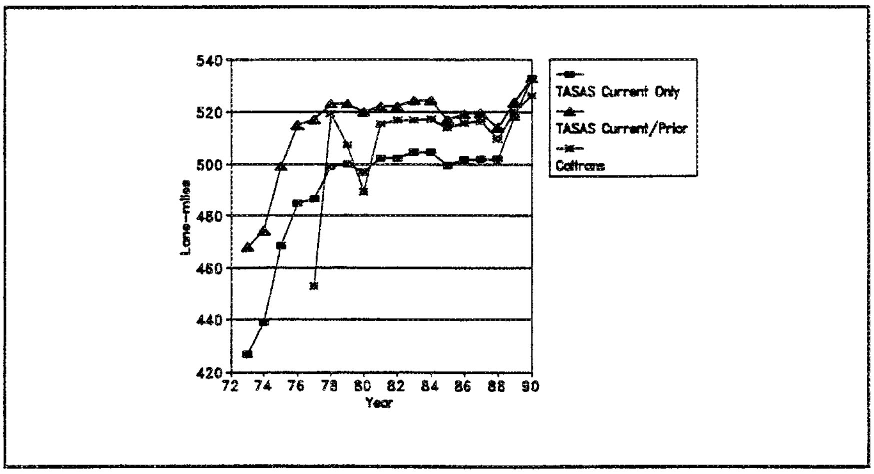

Figure 6-3. Alternative Lane-mile Estimates, Contra Costa

In Figures 6-2 and 6-3 we also find that TASAS lane-mile values change smoothly over time. Since the Current lane-miles did not consider the previous existence of highways that were demolished or abandoned, and Caltrans lane-miles tends to jump up and down and covers a shorter time period, we chose the TASAS lane-mile data derived from both the Current and Prior Highway Files for use in this research.

6.2.3 Aggregation of County Level Data

Although data are available at the county level. significant economic interaction between counties in a given urban area is to be expected. To control for these, data are aggregated into larger regions -- Metropolitan Statistical Areas (MSAs), and Consolidated Statistical Areas (CMSAs)

CMSAs are integrated regions with total populations of 1 million or more. California contains 2 CMSAs -- San Francisco and Los Angeles MSAs consist of integrated regions including at least one contiguously settled urbanized area of population 50 thousand or more. As of 1987, California contained 13 MSAs. All CMSAs and MSAs are defined in terms of counties. Table 6-1 lists California CMSAs and MSAs We use the term "metropolitan" to denote aggregation to the CMSA/MSA level.

Aggregating the county-level data, we computed VMT, POP, PIN, DENSITY, GPRICE, and LMILE at the metropolitan level for the years 1973 to 1990. Both county and metropolitan level data are analyzed and results compared to assess aggregation effects.

6.3 Bivariate Analysis

6.3.1 Correlation Analysis

Table 6-2 shows the correlation coefficients of all variables, measured at the county level, used in this research. The correlation coefficient reflects the degree of association between two variables. The value of 0 indicates there is no linear correlation between the two variables, while the values of +1 and -1 indicate a fully positive or negative correlation between the two variables. The positive sign means an increase in one of the two variables is associated with an increase in the other variable, while the negative sign associates a negative change in one variable with a positive change in the other.

Table 6-2.
Correlation Coefficients, County Level

	VMT	LMILE	POP	PIN	GPRICE	DENSITY
VMT	1.00	0.815	0 978	0.189	-0.087	0.090
LMILE	0.815	1.00	0.781	-0.099	-0 015	-0.074
POP	0.978	0.781	1.00	0.159	-0 034	0.138
PIN	0.189	-0.099	0.159	1.00	-0.239	0.379
GPRICE	-0.087	-0.015	-0.034	-0.239	1.00	-0.013
DENSITY	0.090	-0.074	0.138	0.379	-0.013	1.00

From Table 6-2 we can see that state highway VMT has the strongest correlation with population (POP) and lane-miles (LMILE), and a weak correlation with personal income per capita (PIN). Population density (DENSITY) and gasoline price (GPRICE), which varies by time but not by region, have the weakest correlations with VMT.

There are also correlations between lane-miles (LMILE) and population (POP), and between personal income (PIN) and population density (DENSITY) The relationship between lane-miles and population indicates that counties with larger population usually have more lane-miles of roadways. The relationship between personal income and population density indicates that counties with high population density, which are usually central counties of large metropolitan areas, have a higher personal income per capita. These correlations cloud the interpretation of the VMT correlations discussed above. For example, since POP is correlated with LMILE, the correlation between LMILE and VMT could be "spurious" -- a consequence of both these variables being correlated with POP

Except for moderate correlations with personal income (PIN), gasoline price (GPRICE) and population density (DENSITY) have no significant correlations with other variables. The negative correlation between gasoline price and personal income means that higher gasoline price is associated with lower personal income. This relationship is probably an artifact of secular trends toward lower real gasoline prices and higher real incomes.

Table 6-3 shows the correlation coefficients of variables aggregated to the CMSA/MSA level. Stronger correlations are evident. The correlation coefficient between VMT and population increases from 0.978 to 0.990, and the coefficient between VMT and lane-miles increases from 0.815 to 0.969. These differences reflect interactions between counties, which tend to increase the "noise" in the county-level data.

6.3.2 Graphical Analyses

Bivariate graphs, like correlation, may also suggest possible relationships between any two variables. The relationships suggested by the graphs guide development of statistical models, in which hypothesized relationships can be more rigorously tested.

From Figure 6-4, we can see that VMT generally increases with population. The right-most cluster of points corresponds to the 1973-1990 time series observations of Los Angeles

Table 6-3.
Correlation Coefficients, CMSA/MSA Level

	VMT	LMILE	POP	PIN	GPRICE	DENSITY
VMT	1.00	0.969	0.990	0.580	-0.072	0.613
LMILE	0.969	1.00	0.987	0.499	-0.010	0.538
POP	0.990	0.987	1.00	0.541	-0.032	0.597
PIN	0.580	0.499	0.541	1.00	-0.222	0.694
GPRICE	-0.072	-0.010	-0.032	-0.222	1.00	-0.069
DENSITY	0.613	0.538	0.597	0.694	-0.069	1.00

county, which had a population of 7.0 million in 1973 and 8.8 million in 1990. The second right-most cluster of points corresponds to the 1973-1990 time series observations of Orange county and San Diego county, which had, respectively, populations of 1 6 and 1.5 million in 1973 and 2.3 and 2.5 million in 1990. Each of the other clusters also represents 18-year time series observations of a county. At the bottom left corner, many clusters overlap, so it is generally not easy to distinguish one county from the others. Figure 6-5 plots the same data as Figure 6-4, but on a logarithmic scale. It suggests that there is a linear relationship between logarithm VMT and logarithm population, or in other words that the relationship between VMT and population in log-linear.

Figures 6-6 and 6-7 show relationships between VMT and lane-miles on linear and logarithmic scales, respectively In most counties, there is a positive correlation between these variables in the earlier years, when lane-miles are increasing Notably, however, VMT continues upward after lane-miles stop growing. This may be interpreted in several ways. First, as already noted, the correlation between VMT and lane-miles may be spurious. Second, the latter year increases in VMT may reflect other factors, such as population, which together with lane-miles influence VMT. Third, there may be a lagged effect, so that VMT increases in later years represent delayed responses to earlier lane-mile increases.

Figure 6-8 plots state highway VMT per capita against county population. There is a wide variation in this quantity. The highest value of VMT per capita is 8,500 vehicle miles associated with Orange county in 1978. The lowest value of VMT per capita is 1,500 vehicle miles associated with San Francisco county in 1973. Overall, there is a slight negative correlation between VMT per capita and population. Figure 6-9 shows that the VMT per capita is increasing over time, albeit at different rates for different counties.

Figures 6-10 to 6-15 show plots analogous to Figures 6-4 to 6-9, but at the metropolitan level. In Figure 6-10, the right-most cluster of points corresponds to the 1973-1990 time series observations of the Los Angeles CMSA, which had a population of 10.3 million in 1973 and 14.5 million in 1990. The second right-most cluster of points corresponds to the 1973-1990 time series observations of San Francisco CMSA, which had a population of 5.0 million in 1973 and 6.3 million in 1990. Each of the other clusters represents an 18-year time series observations for an MSA. Observations for the MSAs are clustered together at the bottom left corner of Figure 6-10.

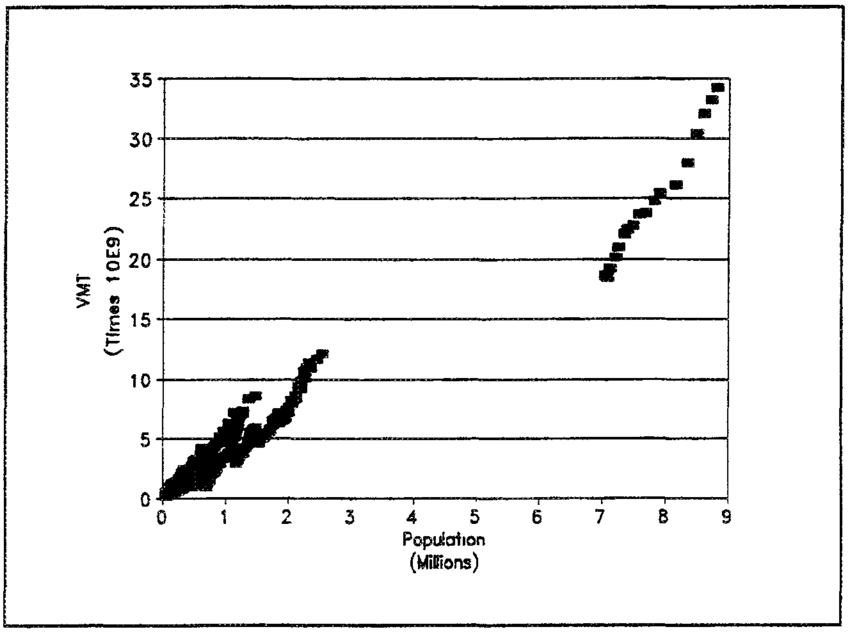

Figure 6-4
VMT vs Population, California Counties

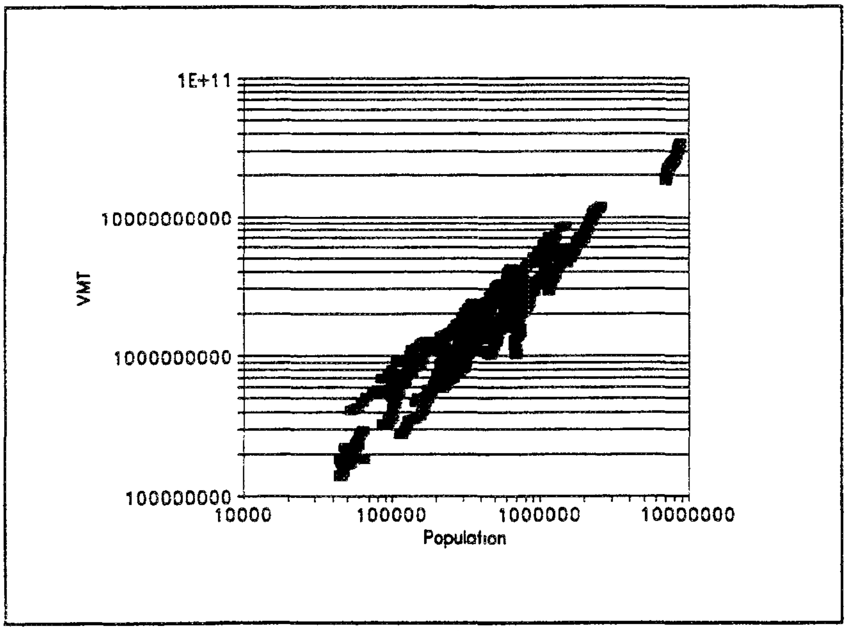

Figure 6-5.
VMT vs. Population (Logs), California Counties

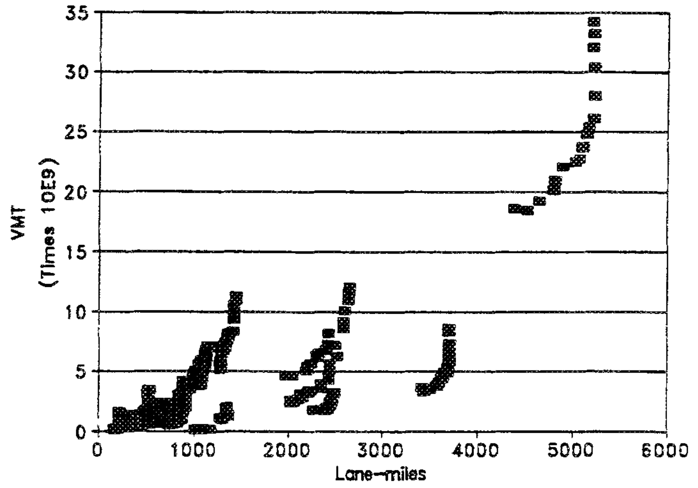

Figure 6-6.
VMT vs. Lane-Miles, California Counties

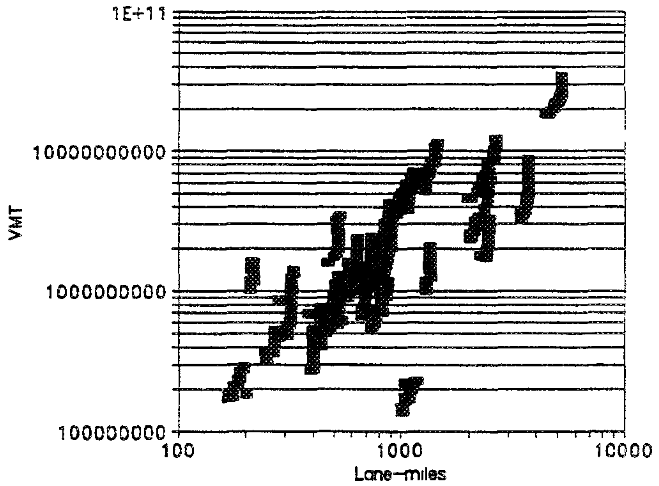

Figure 6-7.
VMT vs. Lane-Miles (Logs), California Counties

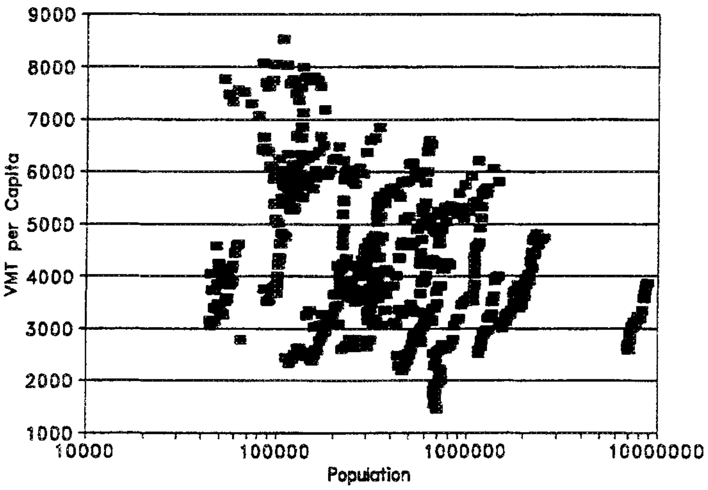

Figure 6-8.
VMT per Capita vs. Population, California Counties

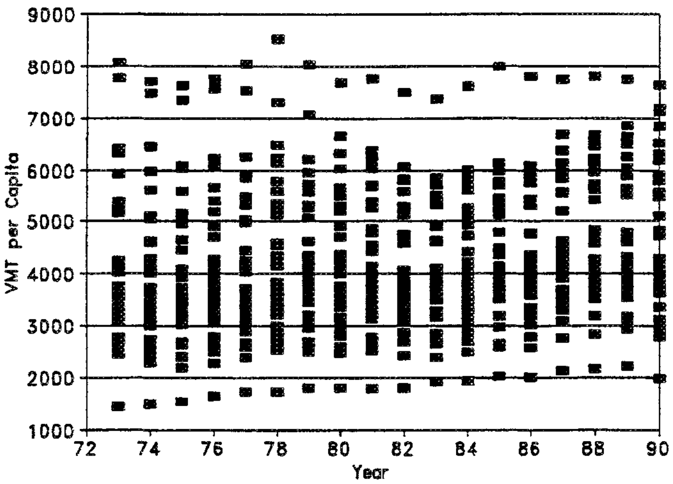

Figure 6-9.
VMT per Capita vs. Year, California Counties

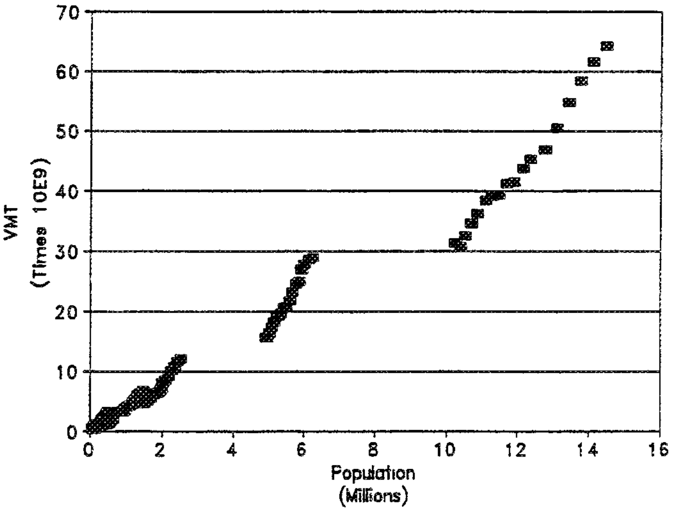

Figure 6-10.
VMT vs Population, California CMSAs/MSAs

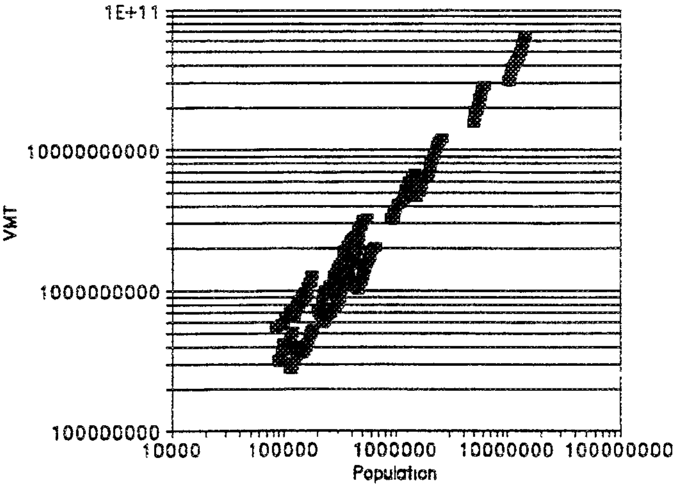

Figure 6-11.
VMT vs. Population (Logs), California CMSAs/MSAs

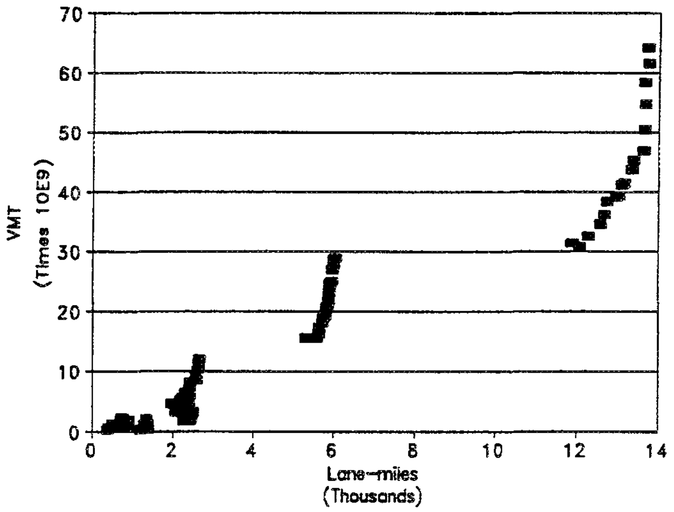

Figure 6-12.
VMT vs Lane-Miles, California CMSAs/MSAs

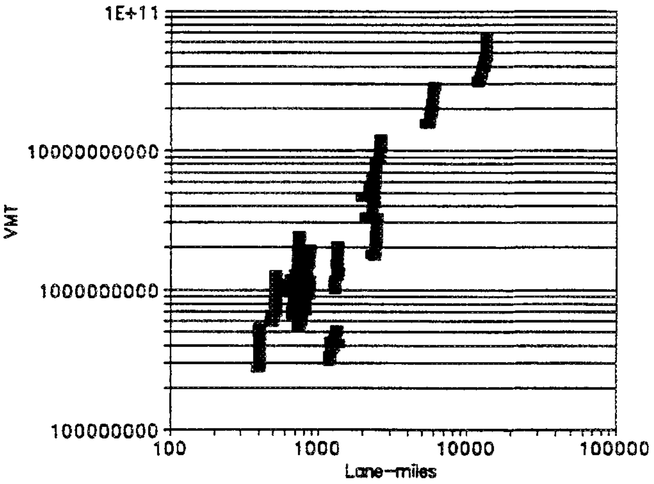

Figure 6-13.
VMT vs Lane-Miles (Logs), California CMSAs/MSAs

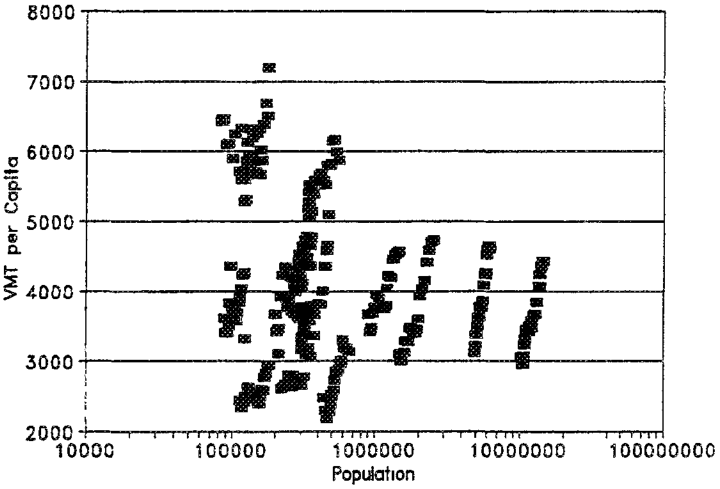

Figure 6-14.
VMT per Capita vs Population, California CMSAs/MSAs

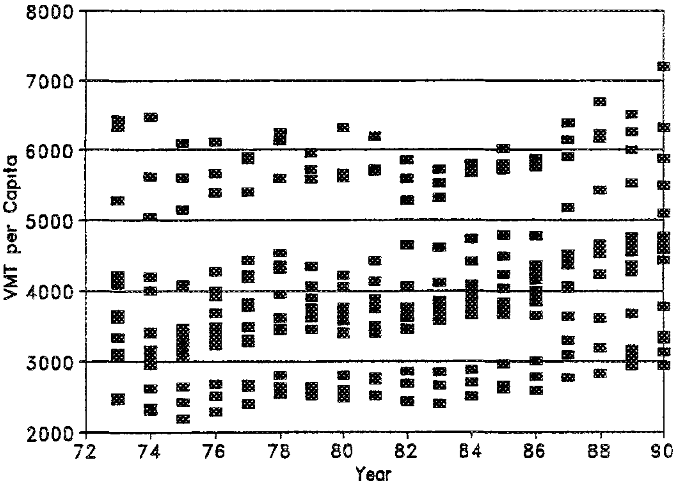

Figure 6-15.
VMT per Capita vs. Year, California CMSAs/MSAs

Figure 6-11, like Figure 6-5, is plotted on a logarithmic scale. Again, a log-linear relationship -- one somewhat stronger than that observed at the county level -- is apparent The greater strength of the metropolitan level relationships is also indicated by Figures 6-12 and Figure 6-13. Figure 6-13, particularly, suggests a far stronger log-linear relationship between VMT and lane-miles at the metropolitan level than does Figure 6-7 at the county level.

Like Figure 6-8, Figure 6-14 suggests a weak, negative, correlation between VMT per capita and population. However, the highest and lowest per capita VMT, 7,200 for Merced in 1990 and 2,200 for Fresno in 1975, are both for smaller urban areas. Figure 6-15 shows that metropolitan VMT per capita is increasing over time, although slowly and unevenly.

6.4 Multiple Regression Analysis of State Highway VMT

6.4.1 Methodology

Each of the bivariate analyses discussed above shares a common limitation -- a failure to control for the effects of variables other than the two specifically considered. As discussed above, this can lead to spurious relationships, as when two variables are themselves unrelated but are both correlated with a third variable. In order avoid these problems, it is necessary to adopt multivariate techniques. These are designed to simultaneously estimate the relationships between a dependent variable and a set of independent ones, and produce unbiased results even when the independent variables are correlated. The multivariate technique employed in this study is multiple regression, which estimates coefficients of a linear function, or model, relating the dependent and independent variables

We estimated several equations, all of them are variations of the general model:

$$\log(VMT_{it}) = \alpha_i + \beta_t + \sum_k \lambda^k \log(X_{it}^k) + \epsilon_{it} \qquad (1)$$

where:

VMT_{it}	is the VMT in area i at time t;
α_i	is an adjustment factor for area i, estimated in the analysis;
β_t	is an adjustment factor for time period t, estimated in the analysis;
X_{it}^k	is the value of explanatory variable k in region i and time t;
λ^k	are coefficients to be estimated;

ε_{it} the outcome of a random variable ε for region i at time t, assumed to be normally distributed with mean 0.

Least squares regression is used to estimate the α_i, β_t, and coefficients λ^k. The model is log-linear, so coefficients can be read directly as elasticities: a coefficient of 0.1 on variable X implies that 1 percent increase in X will increase VMT by 0.1 percent In addition to the ease of extracting elasticity results, the log-linear model is preferred because it always yields a positive value for VMT, and because it predicts VMT to approach 0 when any of the X_{it}^{k}'s with positive (negative) λ^k coefficients approach zero (infinity) This is intuitively plausible, since we expect VMT to go to zero when either population. or income, or lane-miles goes to zero, or when gasoline price goes to infinity Furthermore, the graphical analyses discussed above suggest a log-linear relationship between VMT, POP, and LMILE.

To understand the properties of the above model, in particular its differences from a standard cross-sectional one, it is useful to consider a simplified example. Suppose we have a model relating VMT to lane-miles only, and that we have VMT and lane-mile data (contained in the variable LMILE) for two regions and two time periods. Assume initially that the data are as given in Figure 6-16, the data labels in which consist of the region number (1 or 2) followed by the time period number (1 or 2). In Figure 6-16, neither lane-miles nor VMT change from period 1 to period 2 in either region. Therefore, we cannot determine whether the interregional difference in VMT is a regional effect or a lane-mile effect. Now consider the data in Figure 6-17. In this case, lane-miles in both regions increase at the same rate, and VMT does likewise, from period 1 to period 2. As before, however, these data do not yield information about the effect of lane-miles on VMT, since some unknown portion of the VMT increase could be the result of a time period effect (perhaps, for example, gasoline prices went down between these two periods). If, however, the situation is as appears in Figure 6-18, some inferences become possible. Since in this case lane-miles in region 2 increase more than lane-miles in region 1, we can (assuming our oversimplified model) impute the difference in VMT growth between the two regions to the difference in lane-mile growth. Specifically, we obtain:

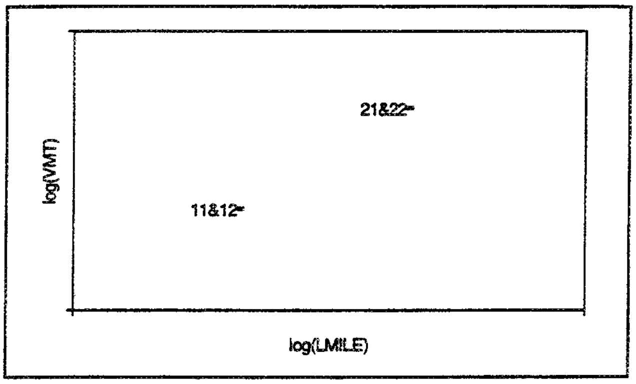

Figure 6-16
Lane-Mile Effect Unobservable Mixed with Regional Effect

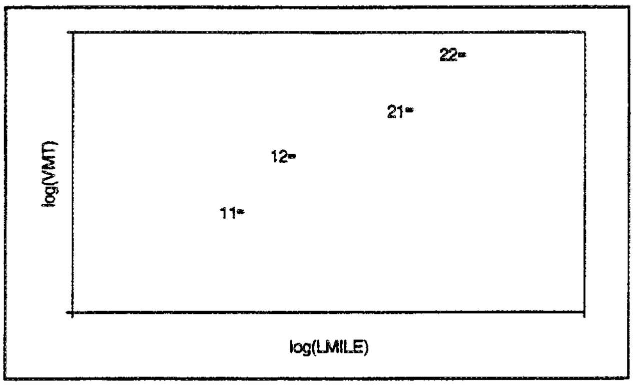

Figure 6-17
Lane-Mile Effect Unobservable Mixed with Regional, Time Period, Effects

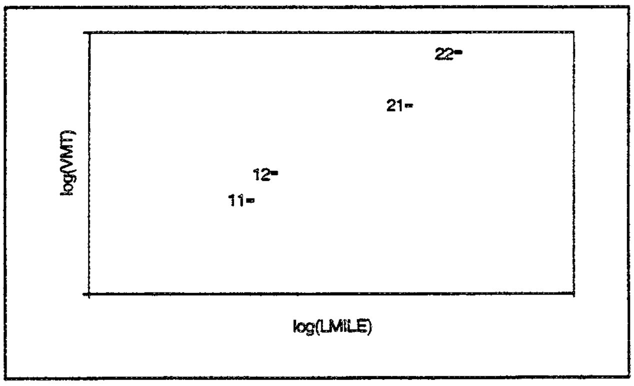

Figure 6-18
Lane-Mile Effect Observable

$$\epsilon_{VL} = \frac{\log(\frac{VMT_{22}}{VMT_{21}}) - \log(\frac{VMT_{12}}{VMT_{11}})}{\log(\frac{LMILE_{22}}{LMILE_{21}}) - \log(\frac{LMILE_{12}}{LMILE_{11}})}$$

where ε_{VL} is the elasticity of VMT with respect to lane-miles

As in the above, simplified, case, the statistical model is estimated by relating differences in VMT growth to differences in lane-mile growth. The statistical model is more complex because it accounts for factors other than lane-miles (for example, population and income), because it deals with more than two regions and two time periods, and because it includes a stochastic error term.

Returning to the two-region, two-period example, if it were known that the regions were identical in every respect except for their quantities of lane-miles, it would be appropriate to eliminate the regional effects from the models. In other words, we might assume that the difference in VMT in Figure 6-16 results from lane-mile differences only. One advantage in doing this is that lane-mile differences between regions are substantially greater than lane-mile changes within regions. Another advantage is that, if VMT adjustments to lane-mile changes occur over time, direct comparison among regions is likely to give a better idea of the long-run relationship between lane-miles and VMT. Finally, if lane-miles added during the period of analysis are of a different character than lane-mile stocks at the beginning of the period, it is likely that lane-mile/VMT relationships based on interregional variation in lane-miles will differ from those based on differences in lane-mile growth within regions. For all of these reasons, it is useful to compare results for models with and without the regional effects captured by the α_i in equation 1. We refer to models with these terms as "intraregional," and those without them as "interregional."

Similar arguments pertain to the time period effects. That is, these effects may in some circumstances absorb effects of lane-mile changes. It is therefore useful to estimate the models with and without the time period adjustment factors (i e the β_t in equation 1).

Excluding the regional and time period adjustment factors, six explanatory variables are considered in the model. The extent of the state highway system is measured in lane-miles

(LMILE). Population (POP) and real per capita income (PIN) are included to control for regional population and economic growth. Population density (DENSITY) is added to capture density effects. We expect that VMT increases with LMILE, POP, and PIN.[2] The net impact of DENSITY is uncertain: it may reduce the need for long-distance travel, but may also imply increased accessibility to the highway system Since the land areas of each region remain constant over time, the effect of DENSITY is absorbed by the regional adjustment factors and POP, so DENSITY can be used only in the interregional model Finally, GPRICE is the average real price of gasoline in California for a given year, and T is a secular trend variable calculated as the difference between the year of the observation and 1972. Since these variables are time but not region dependent, their effects are fully absorbed by the time adjustment factors, and they are consequently included only when the latter are not.

Thus, altogether we have four variants of the general model (1), which we estimate at both county and metropolitan (CMSA/MSA) level. Two of the models, variants 1 and 2, are intraregional, while the other two, variants 3 and 4, are interregional. Within the intraregional category, there is a model with time adjustment factors, variant 1, and a model in which these factors are replaced by GPRICE and T, variant 2 Likewise, there are two interregional models -- variant 3, with time adjustment factors, and variant 4, with GPRICE and T.

Initially the ordinary least squares (OLS) method was used to estimate the coefficients of the model. However, the resulting error terms are found to be autocorrelated -- that is ε_{it} is found to be correlated with ε_{it+1}. When autocorrelation is present, estimation techniques other than OLS yield more reliable results. The technique we employ is the Yule-Walker method, an iterative approach in which OLS is used to generate an initial autocorrelation estimate, which is then used to transform the data in a manner that removes the autocorrelation, which is then used to estimate a new model and autocorrelation coefficient, and so on until convergence is achieved. As it turns out, the results from the two OLS and Yule-Walker methods differ very little. For comparison,

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[2] Readers unfamiliar with log-linear models may wonder why the model uses total rather than per capita VMT as the dependent variable. Since POP is included as a explanatory variable, and log(VMT/POP)=log(VMT)-log(POP), it is easy to convert between a total and per capita VMT model, simply by adding (or subtracting) 1 from the coefficient on POP The choice of which form to estimate is completely arbitrary, and yields identical results for all other coefficients.

the estimated results of both methods are presented for intraregional model with time period adjustment factors (variant 1).

6.4.2 County Level Results

The estimated results of the four model variants, estimated on county level data, are listed in Table 6-4 From Table 6-4 we see that the results of variant 1 and variant 2 are similar, with differences between all common coefficients within the coefficient standard errors.

These results indicate that, for a given region, increasing lane-miles 1 per cent will increase VMT by about 0.5 per cent; increasing population 1 per cent will increase VMT by about 0.4 percent; and increasing personal income 1 per cent will increase VMT by about 0.3 percent. The sum of the elasticities of lane-miles and population is about 0.9, indicating that increasing population and lane-miles 1 per cent (thus keeping the same per capita highway supply and income) will increase VMT by 0.9 percent

From Table 6-4 we see that the results of variant 3 and variant 4 are also quite consistent. These interregional model results, however, differ considerably from those for the interregional model. In particular, the elasticities of population and personal income are higher than those of the intraregional model, while the elasticities of lane-miles are lower.

The differences between the intraregional and interregional model results suggest that different traffic generation mechanisms are at work. The intraregional model captures the effect of changes in lane-miles and other variables on VMT in recent years. During this period, most of the lane-mile increases were for congestion relief, more specifically the removal of bottlenecks. In this situation, the addition of a lane-mile is likely to have a greater impact on level of service, extending beyond the improved segment to segments upstream and downstream where traffic had previously been suppressed due to the bottleneck. Thus, the lane-mile elasticity is higher. The lower population elasticity suggests that recent population growth has not had as strong an influence on state highway VMT as do interregional population differences. One possible interpretation is that recent population growth has contributed less to urban sprawl. Alternatively, more of the traffic generated by recent population growth may be using non-state facilities.

Table 6-4.
Estimation Results for County Level Analysis

VARIABLES	INTRAREGIONAL MODEL (REGIONAL ADJUSTMENT FACTORS)			INTERREGIONAL MODEL (NO REGIONAL ADJUSTMENT FACTORS)	
	TIME ADJ. FACTORS (1)		TIME TREND (2)	TIME ADJ. FACTORS (3)	TIME TREND (4)
	OLS	Y-W	Y-W	Y-W	Y-W
INTERCEPT	-1.474 (-1.10)*	-1.330 (-0.99)	-1.491 (-1.14)	-9.427 (-12.2)	-9.194 (-12.2)
LMILE	0.504 (4.16)	0.501 (5.83)	0.463 (5.36)	0.328 (10.9)	0.323 (10.8)
POP	0.416 (11.1)	0.411 (10.9)	0.428 (11.0)	0.753 (28.6)	0.757 (29.0)
PIN	0.246 (6.10)	0.242 (5.94)	0.272 (7.15)	1.060 (14.1)	1.029 (14.1)
DENSITY	--	--	--	-0.078 (-5.08)	-0.077 (-5.07)
GPRICE	--	--	-0.086 (-6.73)	--	-0.025 (-0.51)
T	--	--	0.019 (14.2)	--	0.006 (2.69)
R-SQUARE	0.9976	0.9976	0.9973	0.9541	0.9533

*t statistics in parantheses.

The income elasticity (ranging from 1.060 to 1.029) of the interregional model is much greater than that from the intraregional model (ranging from 0.242 to 0.272). This implies that people in high income regions travel much more than people in low income regions do. but, within the same region, when people become richer, they tend to travel only slightly more. This difference probably indicates that the income variable is picking up structural differences among counties in the interregional model, while income growth within a county lacks the same structural implications.

The differences between the inter- and intraregional models may also reflect differences between long-term and short-term effects. According to this theory, the interregional model captures the effects of long-standing differences among the regions. Demand for vehicle travel has had a considerable period to adjust to such differences. On the other hand, the intraregional model captures shorter-term VMT response to changes in the independent variables. Although this interpretation may have some validity, it is inconsistent with the result that the intraregional models yield higher lane-mile elasticities than the interregional ones: generally, the longer the period of adjustment, the stronger the effect. Other factors, such as those suggested above, are required to explain the difference in lane-mile elasticities obtained in this analysis.

6.4.3 Metropolitan Level Results

The difference between county level analysis and metropolitan (CMSA/MSA) level analysis is that county level analysis is based on units which may be only a part of a metropolitan area and whose VMT will therefore depend on other counties, while metropolitan level analysis is based on economic units that are relatively isolated and complete. Thus, metropolitan level analysis should be able to avoid the disturbances caused by interaction among units and provide a more complete picture of the relationship between VMT and the other variables. On the other hand, because the size distribution of metropolitan areas is even more skewed than that of counties, the largest areas (San Francisco and Los Angeles), will have a disproportionate influence on the results, particularly in the case of the interregional model.

Table 6-5 shows the results of metropolitan level analysis. In general, the results are similar to those listed in Table 6-4. The main relationships found in the county level analysis appear to hold for metropolitan regions as well. The key differences are lower lane-mile

Table 6-5.
Estimation Results for Metropolitan Level Analysis

VARIABLES	INTRAREGIONAL MODEL (REGIONAL ADJUSTMENT FACTORS)			INTERREGIONAL MODEL (NO REGIONAL ADJUSTMENT FACTORS)	
	TIME ADJ. FACTORS (1)		TIME TREND (2)	TIME ADJ. FACTORS (3)	TIME TREND (4)
	OLS	Y-W	Y-W	Y-W	Y-W
INTERCEPT	-6.730 (-2.98)*	-5.795 (-2.46)	-5.472 (-2.38)	-7.493 (-6.42)	-7.339 (-6.55)
LMILE	0.612 (4.78)	0.576 (4.36)	0.541 (3.98)	0.237 (6.77)	0.237 (6.90)
POP	0.680 (6.39)	0.672 (6.21)	0.682 (6.12)	0.803 (24.3)	0.805 (25.0)
PIN	0.403 (5.43)	0.364 (4.86)	0.351 (5.28)	0.921 (6.90)	0.885 (7.06)
DENSITY	--	--	--	-0.092 (-3.15)	-0.090 (-3.19)
GPRICE	--	--	-0.071 (-3.78)	--	-0.031 (-0.50)
T	--	--	0.013 (4.32)	--	0.012 (4.05)
R-SQUARE	0.9986	0.9987	0.9984	0.9779	0.9775

*t statistics in parantheses.

elasticities in the interregional metropolitan model, and higher population and income elasticities in the intraregional metropolitan model. The former difference suggests that counties with high lane-mileage attract some of their traffic from other counties in the same region -- hence the net impact at the regional level is less than the impact at the county level. The difference in the intraregional income and population elasticities probably reflects spillover effects -- population and income growth in one county causing additional travel in neighboring ones.

6.5 Regression Analysis of Total VMT

The previous analyses considered the impacts of state highway expansion on the VMT on state highways. Highway expansion may also have impacts on traffic travelled on county highways, local streets, and other non-state arteries. If, for example, freeway expansion diverted traffic from local streets to freeways, the impact of the expansion of total VMT would be less than the impact on state highway VMT. Therefore, the traffic impact of freeway expansion cannot be completely assessed without considering traffic changes on non-state highways

Unfortunately, VMT data for non-state highways are less readily available than state-highway VMT data. Data are available for only five years· 1980, 1982, 1986, 1988, 1989. During this period, moreover, there was little change in state highway lane-mileage. This reduces the reliability of our results, particularly those for the intraregional model.

In 1989, VMT on California state highway was 134 billion, while VMT on California non-state highways was 116 billion. Thus, total VMT is about double VMT travelled on state highways. Therefore, if traffic increases on state highways due to highway expansion leave traffic levels on non-state highways unaffected, the state highway lane-mile elasticity of total VMT will be about half that of state highway VMT. If, on the other hand, these state highway traffic increases were accompanied by proportional increases on non-state highways (due perhaps to the increased use of the facilities to access the state highway system, or to traffic generation on the non-state system as capacity is freed due to division to the state system) then the state highway and total elasticities would be the same. Finally, in the event that all increased state highway VMT represented diversion of traffic from the non-state system, total VMT would be completely inelastic with respect to state highway lane-miles. While none of these pure cases will hold completely, they provide a compass for interpreting the results that follow.

Results of the analysis, which was performed at the metropolitan level only, are summarized in Table 6-6. Comparing Table 6-5 with Table 6-6, we see that the LMILE elasticity of total VMT (0.508-0.534) is just slightly less than the LMILE elasticity of VMT travelled on state highways (0.541-0.576) in the intraregional model, and just slightly more (0.259 versus 0.237) in the interregional model. These comparisons suggest that the non-state highways are primarily complementary to the state highways: increased use of the latter leads to increased use of the former.

There is one important difference in the estimation results for the intraregional state highway and total traffic models The t statistics for the latter are quite small, indeed statistically insignificant. One could not, on the basis of these results alone, reject the hypothesis that highway expansion over the 1980-89 period is unrelated to increases in total VMT. On the other hand, the consistency of the total VMT model estimates with those for state highway VMT, as well as the high lane-mile t statistics in the interregional model, suggest that the low intraregional model t statistics result from the small increases in lane-mileage occurring in the analysis period (as shown in Figure 6-12), not because the null hypothesis is actually true.

The population elasticities for the intraregional model of total VMT (Table 6-6) are much larger than those for the intraregional model of state highway VMT (Table 6-5). This suggests that urban areas with strong population growth in the 1980s had even stronger total VMT growth, and that the additional VMT was concentrated on local facilities. Perhaps this derives from the lack of sufficient capacity on state highways to accommodate the influx of traffic in rapidly growing urban regions. The population elasticities in the interregional total and state highway VMT models are quite similar.

6.6 Implications of the Results

To illustrate the implications of our results, we use them to estimate contributions to VMT growth from difference sources during the 1973-1990 time period. Since the data available for total VMT are limited and the results of the last section indicate consistency in the growth patterns of total and state highway VMT, we focus on state highway VMT is this analysis

The intraregional model with yearly adjustment factors (Model 1) is used for these estimates. This model reflects the effect of changes within a region, and has the best fit of all the

Table 6-6
Estimation Results for Metropolitan Level Analysis, Total VMT

VARIABLES	INTRAREGIONAL MODEL (REGIONAL ADJUSTMENT FACTORS)			INTERREGIONAL MODEL (NO REGIONAL ADJUSTMENT FACTORS)	
	TIME ADJ. FACTORS (1)		TIME TREND (2)	TIME ADJ. FACTORS (3)	TIME TREND (4)
	OLS	Y-W	Y-W	Y-W	Y-W
INTERCEPT	-14.588 (-1.05)*	-16.454 (-1.20)	-17.724 (-1.33)	0.296 (0.52)	-0.202 (-0.37)
LMILE	0.440 (0.55)	0.508 (0.64)	0.534 (0.68)	0.259 (5.68)	0.258 (5.72)
POP	1.898 (2.82)	1.980 (2.96)	2.046 (3.08)	0.806 (18.1)	0.802 (18.3)
PIN	0.003 (0.09)	0.004 (0.12)	0.084 (1.41)	0.056 (1.16)	0.139 (2.13)
DENSITY	--	--	--	0.046 (1.39)	0.041 (1.23)
GPRICE	--	--	-0.166 (-1.31)	--	-0.198 (-1.49)
T	--	--	-0.019 (-0.84)	--	0.009 (0.68)
R-SQUARE	0.9950	0.9950	0.9950	0.9922	0.9922

*t statistics in paratheses.

models as well. Results for four periods -- the early 1970s, the late 1970s, the early 1980s, and the late 1980s -- are shown in Figure 6-19.

Figure 6-19 shows that population growth is the most consistent contributor to VMT growth The relative importance of population decreases with time, however. As population becomes less important, "Other" factors become more important. Within the context of this analysis, "Other" is the change resulting from differences in the values of the yearly adjustment factors A reduction in the real price of gasoline of over 50 percent between the early and late 1980s is certainly one of the factors causing these changes. Additionally, factors associated with changing demographics and lifestyles may be playing a role.

Income growth and highway additions are far smaller contributors to VMT growth. Increases in lane-miles contributed about 7 per cent to the 90 per cent increase in state highway VMT over the 18-year period. This reflects both the small amount of lane-mileage added in this period, and the relative inelasticity of VMT with respect to lane-miles

Figure 6-20 estimates the state highway VMT impact from adding an additional lane-mile of highway in different urban regions Estimates based on both the intraregional and interregional models with annual adjustment factors -- variants 1 and 3 respectively -- are presented. Assuming that the additional lane-mile is of a character similar to other recent lane-mile additions, the intraregional estimates are probably more valid Based on the intraregional model, an additional lane-mile in the San Francisco, Los Angeles, or San Diego regions would increase VMT by roughly 2,500 vehicle-miles per day. In smaller cities, expected traffic generation is considerably less -- between 500 and 1,000 daily vehicle-miles

6.7 Summary and Conclusions

Our results indicate that, from a regional perspective, roads do indeed generate traffic. There is a significant statistical relationship between traffic growth and road expansion. We estimate a 0.5 intraregional elasticity of VMT on state highways with respect to lane-miles of state highways in urban regions, and a interregional elasticity of 0.2.

Other factors, such as population and income, also generate traffic Our results indicate that the population elasticity is in the 0.7-0.8 range. The intraregional income elasticity is 0 4 and the interregional one is 0.9. Thus, while roads generate traffic, so do people and money, and

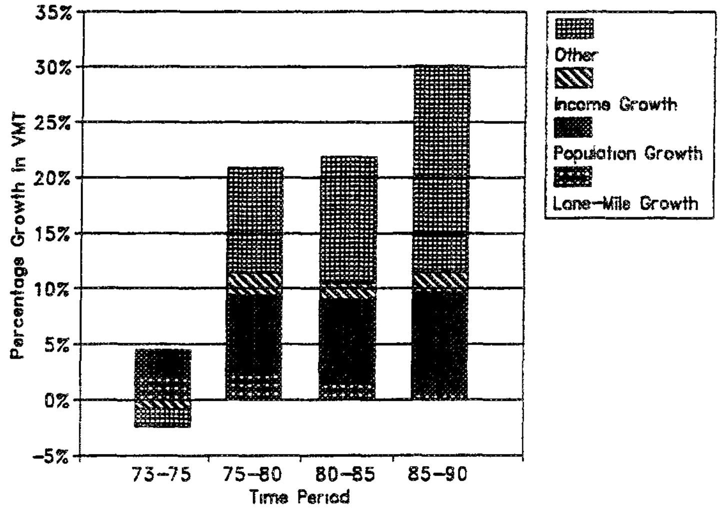

Figure 6-19.
Share of VMT Growth from Various Sources

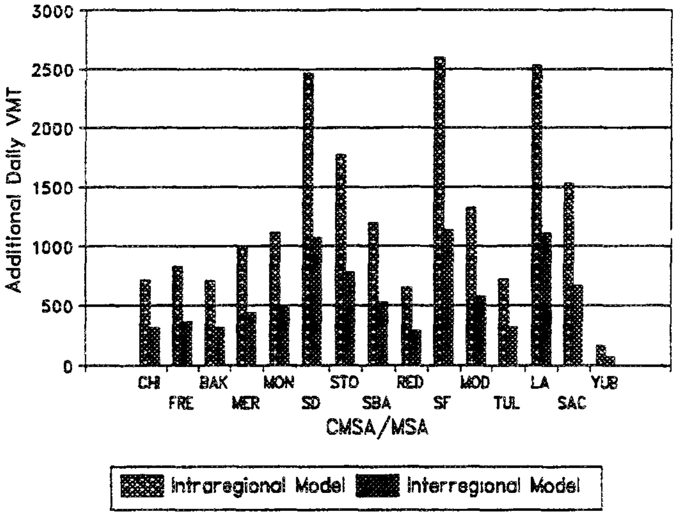

Figure 6-20.
Additional VMT from Marginal Lane-Miles, by MSA/CMSA

indeed these have been the more important factors during the period of study. Population, particularly, because of its strong effect on VMT and rapid growth over the past two decades, has contributed considerably more than lane-mile growth to the VMT increases during this period. An even more important contributor, however, is a set of factors whose effects are captured in the time adjustment coefficients. Declining gasoline prices, increased two-worker commuting, and increases in per capita car ownership are among the factors included here, but their relative importance is difficult to know.

The differences between the intraregional and interregional lane-mile elasticities are contrary to expectation, which is that the latter, since it reflects a longer run response, should be greater Our interpretation of this unexpected result is based on qualitative differences between total lane-miles, variation in which drives the interregional model, and lane-mile additions since 1973, which drive the intraregional model. We conjecture that lane-mile additions during the study period were mostly for congestion relief. The effect of such lane-mile additions has a stronger impact on highway level of service, and thus on traffic. Interregional variation in lane-mileage is less closely related to congestion relief, resulting in a smaller VMT impact.

Even if the higher intraregional estimate is assumed, the elasticity of VMT with respect to lane-miles is well below 1. This implies that increases in lane-miles reduce the ratio of VMT to lane-miles, or the regional "volume-capacity ratio." Assuming that such a ratio is a meaningful indicator of roadway service level at the regional level, we conclude that adding lane-miles improves that level of service. However, it should be reiterated that this is a statistical generalization, not a hard and fast rule that applies to any road project.

Data on total, as opposed to state highway VMT, are limited, and findings are thus tentative. However, we find no evidence that increases in state highway VMT occur at the expense of non-state highway VMT To the contrary, these systems appear to be complements, with increased traffic on state highways leading to increases on non-state facilities as well.

Chapter 7:

Conclusions

7.1 Introduction

The previous chapters have presented results from a set of investigations concerning the relationship between road supply and roadway traffic in urban areas. While unified in theme, these studies were carried out individually and independently, each focussing on a different piece of the supply-demand puzzle. This chapter attempts to fit these pieces together. The picture that emerges is not complete, nor is it definitive, but it is coherent and credible. Furthermore, although our findings do not lead to closure in the debate over the role of roadbuilding in improving urban transportation, they do shed new light on this important policy question. The policy implications of our results are also considered in this chapter.

7.2 Highway Supply and Vehicle Traffic -- The Strength of the Effect

The most important objective of this research was to determine whether increases in road supply generate traffic and, if so, to what degree Two chapters of this report focus directly on this issue. In Chapter 3, we consider how traffic volume on a road segment responds when lanes are added to the segment In Chapter 6, we study the analogous question for a larger geographical unit: how traffic levels in an urban area responds when lane-mileage is added to that area. In both of these chapters, we expressed the relationship in terms of elasticities between traffic and road capacity. What do the various elasticities estimated in these two chapters tell us?

The main results of Chapter 3 are the time dependent traffic-capacity elasticities, summarized in Table 3.5. Although different models yield different estimates, they generally point to an elasticities of 0.3-0 4 ten years after an addition of capacity and 0.4-0.6 16 years after such an improvement. Note that these estimates refer only to the improved segment itself: they say nothing concerning how traffic upstream and downstream from the improved segment, or on other complementary and substitute links, is affected.

The key findings of Chapter 6 are elasticities relating urban area VMT -- on either state highways or all roads -- to state highway lane-miles Unlike Chapter 3, this analysis did not explicitly investigate time dependence. Nonetheless, the intraregional model results from Chapter 6 are roughly comparable to those from Chapter 3, because both relate changes in traffic to changes in road supply. In order to make the comparison, we need to consider how long, on average, the lane-mile additions that drive the intraregional model had been in place at the time of the observations. The intraregional model is estimated over an 18-year period where most of the lane-mile additions occurred over the first 6 years. The estimated elasticity -- in the range 0.5-0.6 for the intraregional, metropolitan level, state highway VMT model (see Table 6-6) -- should thus correspond to a period 6-9 years after lane-miles are added. The traffic-capacity elasticity for this period estimated in Chapter 3 is in the range of 0.2-0.4

Taken together, these results lead to several conclusions. First is the obvious yet important fact that both segment and regional level elasticity estimates are positive, statistically significant, and less than one. Our confidence in the results of the two analyses is bolstered by the fact that, despite being based on such disparate units of observation, they yield results consistent in all these respects. Thus, our results strongly support the conclusion that additions to the supply of state highways generate additional traffic on state highways, but at the same time reduce the ratio of traffic to capacity on these facilities. This implies that adding capacity to the state highway system leads to a system with more, but less congested, traffic.

Second, our results suggest that traffic-capacity elasticities at the regional level are somewhat greater than those at the segment level. Our interpretation of this result is depicted in Figure 7-1. In this simplified case, two points are connected by highways of unit length, and a segment on Route 1, of length α, is widened. Suppose that prior to the project traffic along both Route 1 and Route 2 was uniform and at a level Q vehicles per day, and that the capacity of both routes was C. If the widening reduces congestion, then we expect that after it occurs traffic on the widened segment will increase. Let this increase be ΔQ_1^w. If the change in capacity of the widened segment is ΔC, then the traffic-capacity elasticity at the segment level will be:[1]

$$\epsilon_{QC} = \frac{\Delta Q_1^w / Q}{\Delta C / C} \tag{1}$$

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[1] The key results of this section are most easily derived using the arc elasticity formulas, so these are the ones presented The same principle applies for the point elasticity used in other parts of this report, however.

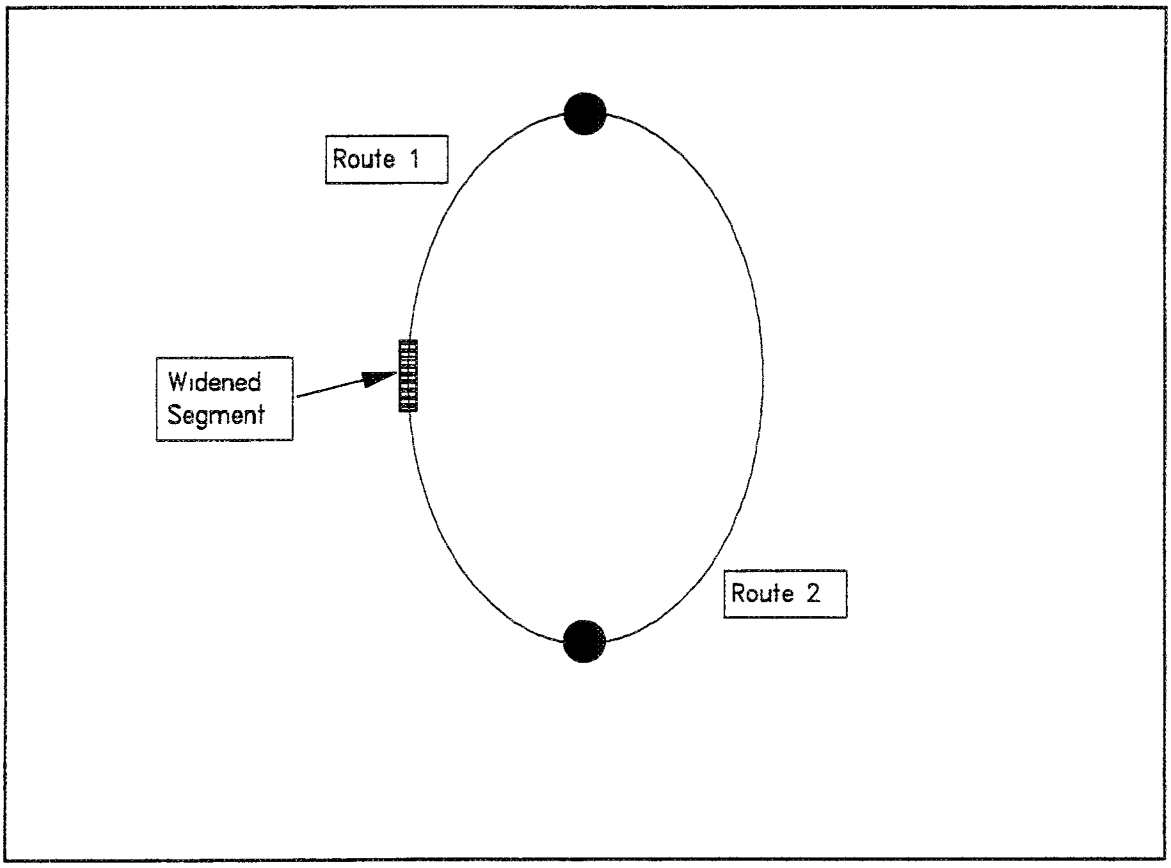

Figure 7-1.
Hypothetical Road System and Widening Project

Traffic on other parts of the network may also be affected by the widening. Traffic on the unwidened part of Route 1 should increase, since some of the trips attracted to the widened portion will also need to traverse this part. Assume the traffic increase on the unwidened portion of Route 1 is ΔQ_1^{uw}. It is also likely that traffic on Route 2 will be reduced as a result of the widening project of Route 1, since this will make the former relatively less attractive. Denote the reduction in traffic on Route 2 as ΔQ_2.

We can calculate the elasticity of vehicle-miles with respect to lane-miles for the above two-route system as:

$$\epsilon_{VL} = \frac{(\alpha \Delta Q_1^{w} + (1-\alpha)\Delta Q_1^{nw} - \Delta Q_2)/2Q}{\alpha \Delta C/2C} = \epsilon_{QC} + \frac{((1-\alpha)\Delta Q_1^{nw} - \Delta Q_2)/Q}{\alpha \Delta C/C} \qquad (2)$$

From equation 2, it is clear that the elasticity of VMT with respect to lane-miles will be greater than the segment level traffic-capacity elasticity when the additional VMT on the unwidened portion of Route 1 is greater than the VMT reduction on Route 2 More generally, the latter elasticity will be greater when the additional traffic on portions of the road network that are complementary to the widened segment exceeds the traffic reduction on substitute routes. Thus, our empirical results from Chapter 3 and 6 imply that complementary traffic gains from capacity expansion exceed traffic losses as a result of route substitution.

Our most robust results on the relation between road supply and traffic concern how the supply of state highways affects traffic on state highways Assuming that such a relationship exists, it is important whether state highway traffic generated from a capacity enhancement represents a net increase in VMT of simply a diversion from non-state highways. We are unable to determine this with confidence, since data on non-state highway VMT are limited. Based on the analysis of total VMT conducted in Chapter 6, it appears that capacity expansion of state highways results in more rather than less non-state highway VMT. We cannot, however, reject the hypothesis that adding state highway capacity has no impact on total VMT. This is an important issue for future research.

Our elasticity results are subject to a number of further qualifications. Most importantly, they represent central tendencies, not hard and fast rules that apply to all projects. The traffic generation of a given capacity enhancement project will depend on factors not specifically addressed in this study including the degree of congestion prior to the project, availability of alternative routes and modes, and the nature of land development and availability of developable land in the area served by the project. The elasticities presented in this study reflect averages, based on the set of road supply additions made to California highways in urban areas over the last two decades. By and large, these improvements focussed on outer suburbs rather than the urban core, and on lane additions rather than the construction of entirely new routes. Thus, it would be inappropriate to apply these results to assess traffic impacts of adding lanes to the San Francisco Bay Bridge, because of its location in the urban core, or of the proposed Route 102 bypass east of Sacramento, because this would be a new facility. Further, as traffic increases raise prevailing levels of congestion on state highways in urban areas, one can expect level of service gains, and hence traffic inducement, from capacity additions to become more pronounced.

Nevertheless, it is useful to compare our results with others cited in the literature. As noted in Chapter 2, earlier area studies, based on cross-sections of urban areas, yield widely disparate results. The best documented analyses based on U.S. cities, those by Koppelman (1972) and Payne-Maxie (1980), obtained elasticities of traffic with respect to highway supply of 0.13 and 0.22 respectively. Both of these studies are cross-sectional, and both use total VMT (or VMT per capita) as the traffic variable. The most comparable results from our study are from the interregional metropolitan total VMT models, estimates for which appear in Table 6-6. The lane-mile elasticity of VMT estimated from these models is 0.25. This is higher than both the Koppelman and the Payne-Maxie estimates, but very close to the latter. Moreover, all three estimates are quite low, bolstering the conclusion that, on a cross-sectional basis, regional traffic is inelastic with respect to highway supply. However, we have argued that cross-sectional models do not answer the essential question, which is how traffic in a given area would change if road supply in that area changed. This is the question that our intraregional models are intended to address, and it is notable that the elasticities obtained from these models are considerably higher. In light of the disparity we find between the lane-mile elasticities from our intraregional and interregional models, we conclude that cross-sectional analyses such as those of Payne-Maxie and Koppelman, as well as our own interregional models, do not give reliable estimates of the sensitivity of traffic to road supply in an individual region.

The cross-national city comparisons of Newman (1989) suggest an elasticity of 0.7, assuming that all differences in per capita vehicle travel can be traced to differences in per capita road supply. It is hardly surprising that we estimate elasticities well below that implied by Newman's international comparisons. As has been repeatedly noted, the value of 0.7 we calculate from his results is based on a simple comparison of VMT and roadway per capita for two extreme clusters of cities -- one consisting of places with heavy congestion little vehicle travel per capita, and the other of cities with the opposite characteristics. For the calculated value to be accepted, one must assume that such variables as gasoline price, historical development patterns, land availability, income, and transit supply are either unimportant or derive entirely from differences in road supply. Furthermore, even with these assumptions, the elasticity obtained is likely to hold only for the very long run, not the adjustment period of a decade or so considered in our analyses.

Perhaps the most interesting comparisons are between our results and those of Ruiter et al. (1979). Their analysis, like ours, looks at the effects of adding highway capacity in a given region. Moreover, both case study projects considered by Ruiter are incremental, adding 69 and 50 new lane-miles respectively. One is the widening of Route 24 east of Oakland. Contrary to our results, it is found that this project did not increase daily traffic at the regional level (although it did increase peak traffic). On the other hand, the other project, a new segment of eight-lane freeway extending Route 24 into Oakland, was found to have a traffic generating impact equivalent to a VMT-lane-mile elasticity of 0.38. This is less than, but fairly close to, the estimates obtained from our intraregional models. There are several possible reasons for the Ruiter elasticities being less than our own. First, the Ruiter study considers total traffic rather than traffic on state highways. It is hardly surprising that total traffic is less sensitive to state highway lane-miles than state highway traffic is. While our own total VMT results do not indicate such a lower elasticity, these are, in the case of the intraregional model, statistically unreliable. A second possible reason for Ruiter's elasticity estimates being lower is that their model neglects land use impacts of the capacity enhancements. As discussed below, our analysis of building permit activity, presented in Chapter 4, suggests that such impacts may be substantial. There may be additional mechanisms by which road supply affects traffic that the Ruiter model fails to capture as well -- one advantage to the empirical approach taken in the present study is that the results implicitly account for <u>all</u> the causal connections between road supply and traffic.

Finally, the Ruiter estimates are for a specific time period, 1975, when traffic congestion, and thus the effect of capacity changes on level of service, was far less than it is today, or was, on average, over the 1973-1990 time period covered in our area-wide analysis.

In summary, our results diverge from previous studies, but they do so for understandable reasons. We believe the low elasticities obtained from the cross-sectional studies of Koppelman and Payne-Maxie should be discounted, since it appears from our own results that cross-sectional analyses lead to low estimates of the relationship between VMT and lane-miles. We also believe that the high elasticity calculated from the Newman study is invalid, since it attributes the entire difference in traffic between two vastly different groups of cities to the difference in road supply The implications of the Ruiter study are less clear. On the one hand, the divergence between that study and our own could reflect our focus on state highway as opposed to total traffic. On the other hand, it could be that the Ruiter model neglects some of the mechanisms through which lane-mile additions generate new traffic, or that the analysis year of the study is not representative of present conditions.

7.3 Road Supply and Land Use

While we have established, and measured, the impact of road supply on traffic, we have not attempted a complete account of the mechanisms that mediate this impact. As noted in Chapter 2 (Section 2.2), the number of possible mechanisms is quite large, and there is a voluminous literature concerning them Large-scale regional transportation models are clearly required in order to assess the relative importance of the mechanisms, but in our opinion a model that can reliably do this has yet to be invented. We do, however, devote considerable study to one particular mechanism -- land-use change. Our attention to this issue is motivated by several factors. First, since conventional regional transport planning models do not include this linkage, its existence and magnitude has important implications for the adequacy of such models for predicting the impacts of road improvements on VMT. Second, data for assessing land-use impact are readily available. Third, it is feasible in this context to make direct queries of the decisionmakers -- planners and developers whose actions largely determine land use outcomes.

Our statistical analyses and decisionmaker interviews yield decidedly different findings. The panel analysis of building permits indicates that capacity expansion projects occasion sharp increases in residential and commercial development, with increases in building permit activity of approximately 50 per cent in each case. Yet both planners and developers state that capacity enhancements played a negligible role in their decisions, even though highway access is an important factor in them. Rarely do different modes of inquiry yield such startlingly contradictory results.

How might these findings be reconciled? The statistical analysis is subject to spurious correlation, but we do not know of any specific reason for such a problem in this particular analysis Like the traffic analyses, the permit analysis was based on a panel data set. Although the results for any one corridor could be greatly influenced by events coincident with the capacity enhancement, a panel data set is less subject to such distortions. Unless and until a specific source of spurious correlation is found, the empirical links between capacity and permit expansion found in our study should be accepted.

The question thus becomes. how can this link exist without the knowledge of land use planners and developers? Two types of explanation are possible here. First, the set of informants we interview may not accurately represent planner and developer viewpoints. Several of the projects considered in this part of the study were completed a decade or more ago, an interval over which considerable turnover of personnel and dimming of recollections can occur. Also, since we focus on the Bay Area for developer contacts, the views of the developers described in this report may not be representative of the state as a whole.

Second, informants may not perceive linkages between development and highway capacity increases because these are indirect. For example, the influence of land prices on development decisions is widely acknowledged. Thus, if these prices responded to roadway improvements, this could lead to an impact on development. Additionally, since informants recognize the impact of traffic conditions on local roads on the development process, improvements in these conditions resulting from a state highway capacity enhancement could facilitate development. These local traffic improvements could occur as a result of diversion to the improved state highway, or a reduction of queuing on access routes to it. Lastly, several developers state that commute times to employment centers, as well as other accessibility factors, play an important role in development decisions. Although one might expect that the link between capacity expansion and accessibility increase would be obvious to these individuals. perhaps this is not the case. In other words, developers may respond when a freeway improvement brings an area within a 30-minute commute of an employment center without knowing of the role of the improvement in providing this level of accessibility.

Assuming that the statistical results present an accurate picture of the land use impacts of capacity increases, what are the implications for traffic generation? Clearly, these land use changes will lead to greater traffic potential along the improved corridor. However, this does not in and of itself imply an increase either in corridor or regional traffic. Along the corridor, increases in tripmaking resulting from land use intensification may be partly or wholly offset by reductions in average trip lengths. At the regional level, the crucial questions are whether the development would have occurred in another part of the region if the freeway capacity expansion had not occurred, and if so where. Although we cannot answer these questions directly, it stands to reason that development spurred by the expansion of a highway will rely more heavily on highway travel than other types of development. In sum, there is strong reason to believe that the land use impacts found in this study imply some increase, at both the corridor and regional level, in the quantity of vehicle trips. The impact on VMT is less clear, because of the potential for suburban development, when suitably balanced between residential and non-residential land uses, to reduce trip lengths.

7.4 Policy Implications

The fundamental policy question motivating this research is: "Should we expand highway capacity in urban areas to alleviate congestion and reduce emissions?" As was anticipated, we have not reached a conclusion on this issue in the current study. Nonetheless, we believe that our findings can lead to a more informed, and less polarized, debate on the issue. Toward that end, in this section we assess how both roadbuilding advocates and their opponents might temper their positions in light of our findings.

To the advocates, we emphasize that the capacity enhancement of existing facilities, like the construction of new ones, generates traffic both on the improved section and in the larger urban area. The traffic generating effect is not confined to a few "unusual" projects, but a widespread phenomenon. There is also evidence -- though admittedly weak -- that impact is more than the mere shifting of traffic from one part of the network to another -- indeed there appears to be a net increase in traffic on the unimproved links as well as the improved ones. The magnitude of the impact grows with time in such a way that it easy to confuse the traffic generating effect of improvements with "inevitable" secular increases in traffic. Nonetheless, these effects can be separated statistically, and the former is significant even under the most conservative estimates. Finally, there is evidence that conventional transportation planning models tend to underestimate traffic generation resulting from capacity enhancements, at least in part because they fail to adequately account for land use impacts.

To opponents of roadbuilding, we stress that, despite their traffic generation impact, capacity enhancement projects result in reductions in volume-capacity ratios, and thus improved level of service, over an extended period. Increases in traffic fall well short of absorbing the additional capacity provided. In the first several years after a capacity addition, the additional traffic is so low that net reductions in emissions and energy use are highly likely As time goes on, traffic inducement increases and net impacts become less apparent, but our results suggest that even 20 years after an improvement service levels are markedly higher than they would have been without the project In short, roadbuilding can hardly be viewed as a futile effort to satisfy an insatiable demand, except perhaps in the very long run.

Thus it emerges that the valuation of highway expansion benefits depends on the time horizon and the weight given to short-term and long-term considerations. The pro-expansion position gives priority to the near term improvements in service and reduction in environmental impacts -- along with other benefits -- presumed to result from these. Their opponents prefer to accept the adverse consequences of congestion in the present in the hope that it leads to a future of reduced automobile dependence and impact

Our study falls far short of what would be required to fully inform such a debate. Ideally, one would be able to forecast emissions over time under different policy scenarios. These forecasts would need to consider both the response of traffic volume to capacity additions and the associated emissions. Such an analysis might reveal that capacity additions would be a dominant strategy from an air quality viewpoint, on the grounds that by the time traffic has built up in response to the new capacity, vehicle emissions will have been reduced to the point of negligibility. Alternatively, it may turn out that capacity expansions can reduce emissions in the present only at the cost of greater emissions in the future. Such a trade-off would be difficult indeed, given the complexity of the mechanisms by which emissions affect life on this planet

Appendix A.

Caltrans Comments on Draft Report

A.1 Introduction

A draft of this report was submitted to Caltrans for review and comment. The comments, as received, are included at the end of the appendix. Below, we offer responses to the main criticisms of the reviewers. In general, we were struck by the sensitivity of the reviewers to the finding that capacity enhancements generate traffic. In contrast little attention was given to the finding that the traffic generation effect is fairly modest, which implies that adding capacity is likely to result in long-term reductions in congestion. We believe that in the current policy environment, the latter conclusion is more notable than the former one Although further study is needed, we believe that our findings strengthen the case of those who advocate roadbuilding as a solution to urban transportation problems.

A.2 Responses to Specific Comments

A.2.1 Steven Borroum

Comment: The report should focus more on the relationships to VMT per Capita.

Response: In Chapter 6, county and metropolitan VMT is modelled as a function of lane-miles, population, and other variables. As footnote 2, page 6-21, indicates, the log-linear total VMT models developed in Chapter 6 are easily translated into per capita VMT models. Furthermore, all other coefficients of the models are unaffected by this translation. In Chapter 3, we do not explicitly control for population, but do control for overall trends in traffic growth.

Comment: When considering the effect of the price of gas, the report must account for fuel efficiency gains, and changes in one's ability to purchase gas.

Response: It is true that gasoline price does not fully reflect the cost of driving. However, it is not obvious that it is appropriate to correct by factoring in fuel efficiency. The fuel efficiency gains of the last two decades have been achieved at the cost of higher purchase prices for vehicles and smaller, less comfortable, interiors. Thus a gasoline price variable that incorporate fuel efficiency may understate the disincentive to driving from higher gasoline prices, just as the variable we use may overstate this effect. With regard to changes in ability to purchase gas, the income variable should capture this effect. Finally, the effects of the cost of driving should be fully captured by the time period adjustment factors we employ in variants 1 and 3 of our VMT models, since there is little regional variation in this cost.

Comment: The report concludes that since two parameters are increasing (VMT and lane-miles), they must be related The report needs to more closely examine cause/effect relationships.
Response. We have gone to considerable lengths to avoid this obvious fallacy. In the area-wide model (Chapter 6), we include time period adjustment factors or a time trend variable in all of our models. We also control for other factors, such as population and income, that clearly affect VMT. While there is always the possibility that our results are distorted by spurious causation, this possibility is vastly reduced by the precautions we have taken.

Comment: Does six years make a trend?
Response: Our data set consists of 18 years of data for counties in 15 metropolitan areas Even if only six of years give useful information, this give 90 observations at the metropolitan level, and over twice that many at the county level. This amount of data, even if all confined to a six-year period, can certainly show a trend. We admit, however, that the relationships between VMT and lane-miles (or any of the other variables included in our model) found in our analysis are subject to change in the future.

Comment: To minimize the uncertainties between areas, one should avoid comparisons and conclusions between such areas related to total VMT.
Response: By including regional adjustment factors in our intraregional models, we control for the persistent differences between regions, concern over which seems to motivate this comment. We do make comparisons between regions, but the comparisons involve changes in lane-miles and changes in VMT. This is much less prone to misinterpretation than the pure cross-sectional analysis that the comment implicitly, and correctly, criticizes. Furthermore, if regions were analyzed individually rather than as part of a panel, we could be accused of confusing lane-mile

effects with time period effects (see page 6-18). The pooled cross-sectional analysis is unique in its ability to distinguish regional and time-period effects from those of other variables.

In addition to his specific comments on our report, Mr. Borroum offered an "Alternative" analysis. Our response to this analysis is a follows:

1. The use of expenditure rather than lane-mile data adds uncertainty. There is substantial variation in construction cost both over time and between projects. We strongly disagree that expenditures is "the best available indicator of when system capacity was added."

2. We concur that population growth leads to VMT growth. Our own analysis shows that population has contributed much more to VMT growth in the past two decades than lane-mile growth has.

3. It is inappropriate to relate comparisons of per capita VMT growth in an area to its share of total highway expenditures. Although Sacramento had a smaller share of these expenditures than the other areas, it also has a smaller population.

4. We are joyful that Mr. Borroum sees how his data could be construed to support the hypothesis that roads generate traffic, based on the comparison between Los Angeles and San Francisco. We also agree that the comparison between these areas points to the potential air quality benefits of highway investment. If more of the San Francisco traffic growth resulted from capacity increases, while more of the Los Angeles traffic growth derived from population increases, we would certainly expect the San Francisco area to attain more improvement in air quality.

A.2.2 Greg King

Comment: The study should be critiqued by others outside Caltrans

Response: We agree that it should and have no doubt that it will However, this is most appropriately done after, rather than before, publication. In our preface, we include the usual disclaimer that the study reflects the views of the authors, not of Caltrans.

Comment: The study seems to deviate considerably from those that went before it.

Response: Given the wide range of findings from previous studies, results of any new study are inevitably going to deviate from some of the earlier ones. We cite one earlier study, Payne-Maxie

(1980), with which our results are quite consistent. Among the others, our estimates of the sensitivity of traffic to highway supply are higher in some cases (Koppelman, 1972) and lower in others (Newman, 1989).

Comment: The study does not take into account the influence of expanded car ownership and increased economic activity on the volume of traffic.
Response: Our area-wide models include income as a measure of economic activity. Increased automobile ownership (insofar as it is unrelated to income gains), will be captured by the time period adjustment factors.

A.2.3 Norm Roy

Comment: The study deals with improved state highway segments only and ignores the impacts on non-state highways.
Response: This is generally true, and we admit that this is a limitation. Nonetheless, since state highways are Caltrans' primary responsibility, we consider our findings relevant. Also, the limited evidence available suggests that traffic diversion from non-state facilities is not the primary source of traffic generated by state highway capacity enhancements (see section 6.5).

A.2.4 Chuck Chenu

Comment: Both traffic level and traffic growth models use data from the Count Book and therefore the values derived include BOTH induced (if any) and diverted traffic. The report uses the term "induced" which is misleading.
We feel it is appropriate to use the term "induced" to include any additional traffic on an expanded road segment that results from the expansion. We view diverted traffic as a subset of induced traffic. This is obviously a question of semantics and we make it very clear that our estimates of traffic inducement in Chapter 3 include traffic diverted from other facilities.

Comment: The freeway-corridor land-use model is very complex and perhaps contains too many variables
Response: Although many variables were initially considered, principal components analysis was

used to limit those actually included to a more manageable number. There is a fine line between including too many variables, making the model overly complex, and omitting relevant variables, opening the possibility that an apparent relationship between capacity expansion and development is really due to some omitted variable.

Comment: I think this relationship (between capacity expansion and permit activity) is secondary with both the addition of capacity and the number of building permits related to an independent factor or policy decision

Response. This is certainly possible. Note however, that land use is controlled at the local level, while highway investment decisions are made at the county, regional, and state levels Land use and transportation planning are often criticized for their lack of coordination, whereas this comment suggests that they are so well coordinated that highway expansions projects are completed just in time to accommodate spurts in development activity

Attachment: Caltrans Comments as Received

STATE OF CALIFORNIA - BUSINESS, TRANSPORTATION AND HOUSING AGENCY PETE WILSON, *Governor*

DEPARTMENT OF TRANSPORTATION
1120 N STREET
SACRAMENTO, CA 95814
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August 26, 1993

Mr. Adib Kanafani, Director
Institute of Transportation Studies
Univ. of Calif., Berkeley
109 McLaughlin Hall
Berkeley, ~~CA 94720~~

Attention Mark Hansen

Dear Mr. Kanafami:

Draft Report - "The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Impacts"

Thank you for the opportunity to review the subject draft report. We have all worked hard to get the report to this point, and the subject matter is even more "in-the-spot-light" now than when we started three years ago.

I have collected comments on the report from a variety of experts in the Department. These are attached. At minimum, I would hope that you include the comments and responses within the final report.

If desired, I could arrange a "group discussion" of the report.

In addition to finalizing this report, and preparing some reader friendly summary report(s), I would hope that we are able to carry forward with further research and an expanded review process.

Thank you for your cooperation and assistance, and I expect to hear from you as to the final disposition of the report.

Sincerely,

J. Steven Borroum

Attachment

August 19, 1993
By: J. Steven Borroum

SUMMARY OF

AND

COMMENTS ON

Draft Report Prepared by

University of California - Berkeley

Institute of Transportation Studies

Titled

"The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Impacts"

SUMMARY OF REPORT

The question is asked ...

> "Should we expand highway capacity to alleviate congestion and reduce emissions?"

The response is,

> "In San Francisco, Los Angeles, and San Diego, about 2500 additional VMT per day would be generated by an additional lane-mile."
>
> "There is a significant statistical relationship between traffic growth and road expansion. We estimate a 0.5 intraregional elasticity of VMT on state highways with respect to lane-miles on state highways in urban regions, and a interregional elasticity of 0.2."
>
> "... that the capacity enhancement of existing facilities, like the construction of new ones, generates traffic both in the vicinity of the improvement and in the larger urban area."

The report goes on to state,

> "... while roads generate traffic, so do people and money, and indeed these have been more important factors during the period of study."

> **"In the first several years after a capacity addition, the additional traffic is so low that net reduction in emissions and energy use are highly likely."**
>
> **"... road building can hardly be viewed as a futile effort to satisfy an insatiable demand, except perhaps in the very long run."**

COMMENTS ON REPORT

1. California's population growth rate over the last 40 years of approximately 2.6% annually seems to be unaffected by transportation and economic factors (see attached). Therefore, it is a foregone conclusion that overall, VMTs will increase as driven by an ever increasing population. Only when the VMTs are examined on a per capita basis (attached), do we see any significant deviation from the steady grow patterns exhibited by both the population and total VMT trends. **The report should focus more on the relationships to VMT per Capita.**

2. Gasoline price and personal per capita income are examined for relations to travel growth, and are noted as generally being weak. In our examination, the "out of pocket" costs to the driver were seen as a function of both the price of gas and the vehicle's fuel efficiency. It is mandatory that one account for the dramatic increase in the total vehicle fleet's fuel efficiency when examining the true cost of gasoline. Further, we believe that one's ability to purchase the gas must also be accounted for. Therefore, we also adjusted for personal per capita income. The resultant factor was what we called the "driving affordability index." (See attached) As the index goes up, so does one's ability to purchase vehicle miles traveled. **When considering the effect of the price of gas, the report must account for vehicle fuel efficiency gains, and changes in one's ability to purchase gas.**

3. Once one considers the additional factors noted in #1 and #2, and compares the results, there appears to be a statistically significant relationship between the affordability index and the per capita VMT (see attached). When there is a **change** in the affordability index, there appears a corresponding **change** in the per capita VMT. This is more than can be stated for the relationships examined in the report.

In the mid and again in the late 1970s, an affordability index drop lead to a drop in the per capita VMT. We have just recently seen the same event occur. Starting in the late 1980s, we see a drop in the affordability index leading to a drop this past year in the per capita VMT.

Largely, the report concludes that since two parameters are increasing (VMT and the increase in lane miles), they must be related. **The report needs to more closely examine causal/effect relationships.**

4. The UC Berkeley researchers were only able to identify maybe 2 to 6 years where there seems to be a significant increase in lane-miles. There are serious questions whether this small of a time frame is sufficient to identify relations. **Does 6 years make a trend?**

5. The report draws conclusions from the comparison of VMTs between counties and metropolitan areas. Such cross comparisons between different areas invites what could potentially be significant uncertainties due to the fact that different areas in California have varying amounts of State Highways and varying amounts of tourists and other

external based trips. To minimize the uncertainties between areas, one should avoid comparisons and conclusions between such areas related to the total VMT.

ALTERNATIVE

The analysis should focus on a comparison of trends and relationships among the areas. For example (see attached), the per capita VMTs for the Bay Area (Area 1) and the LA area (Area 2) both grew from 1975 to 1990 by approximately 43% and 42%, respectively. Similarly, the per capita VMT growth rate patterns for San Diego County and Sacramento County were notably higher, growing at 51% and 57% respectively. Maybe a more central question might be, why are the growth rates in San Diego and Sacramento County higher than the two larger metropolitan areas?

% GROWTH BETWEEN 1975 AND 1990

	LA	SF	Sac	SD	Statewide
Population	38	23	52	58	39
Per capita VMT	42	43	57	51	38

Expenditures on State Hwys between 1975 & 1990
as a % of the total expenditures between 1953 & 1990

	LA	SF	Sac	SD	Statewide
	16	19	9	19	19

(Note: if the expenditures were annually uniform, this would be 39% for all areas)

TOTAL PER CAPITA EXPENDITURES ON STATE HIGHWAYS, 1990 $'s

	LA	SF	Sac	SD	Statewide
between 1953 & 1975	2241	2508	3036	2921	2825
between 1953 & 1990	1927	2504	2203	2301	2500

I include the consideration of expenditures for capital improvements on the State Highway System, as I continue to see this as the best available indicator of when system capacity was added. While certainly a 1990 dollar spent in 1960 bought more capacity than the same dollar spent in 1990 (due to added "standard" features being involved with construction in recent years), when comparing expenditures between areas, within the same time periods, this variable is negated.

What might we hypothesize from this information?

The first hypothesis might be that the more rapidly growing areas, in terms of population, seem to have a more rapid growth in per capita VMT. Note that Sacramento and San Diego experienced rapid growth in both population and per capita VMT. However, when comparing Los Angeles and San Francisco, the Los Angeles area's population grew much more rapidly, but the per capita VMTs grew at nearly identical rates in both areas.

The second hypothesis might be that within the 15 year period between 1975 and 1990 there appears to be no relationship between added capacity and either population or per capita VMT growth rates. During these years, a greater proportion of the State Highway system's total capacity was added in San Francisco and San Diego as compared to Sacramento. Yet with the lowest proportional increase in capacity during these years, Sacramento experienced the highest increase in per capita VMT.

It may behoove us to look further into the expenditure/capacity element on both of these hypotheses.

On the first hypothesis, it appears that the San Francisco area has consistently invested more in added system capacity as compared to the Los Angeles area. This may have created more "available capacity" in San Francisco area, so that even with a lower population growth rate, this area realized the same growth in per capita VMT as the "more congested" Los Angeles area.

Lets consider this point a bit further relative to the air quality element of the initial research question ... an element that the UC Berkeley draft report did not explore.

In the Los Angeles area, the peak ozone levels have decreased from their high point in the '60's approximately 48% to the 1990 levels. Whereas, in the San Francisco area, the similar high levels from the '60's have reduced by approximately 62%.

While the air quality gains in both areas is significant, it would appear that the additional "available capacity" in the San Francisco area, and the area's continued high investment rate in the State Highway System, has positively contributed toward cleaner air. This is also suggested, but from a different approach, by my report of April 14, 1992, "Discussion Paper, State Highway Improvement Projects, Growth, and Air Quality."

On the second hypothesis, the Sacramento inconsistency may be at least partially accounted for by the fact that prior to 1975, Sacramento's investment into State Highway system capacity was substantially higher than the other areas. In 1975, Sacramento may have had a comparatively large amount of "available capacity;" thereby, being able to support a comparatively large increase in per capita VMT with limited additional capacity.

In summary, I would put forth the following hypothesis:

- **The continued increase in our per capita VMT is largely due to our continued good economic fortune of the last 40 years.**

- **As a metropolitan area's population increases, this growth is a driving force to accelerate the growth in the per capita VMT.**

- **Added highway capacity is not a major influence on either a metropolitan area's population or per capita VMT growth rates.**

- **Added highway capacity is a positive influence on a metropolitan area's air quality.**

CONCLUSION

The data warrants further exploration. Concise, reader friendly report(s) should be prepared summarizing the findings and hypothesis. These reports should be published and distributed to the transportation and air quality decision makers.

NOTE

THE ATTACHED DATA IS AGGREGATED BY COUNTY. SOME COUNTIES ARE GROUPED TO BETTER REPRESENT A REGIONAL PERSPECTIVE.

AREA 1 IS THE GREATER LA AREA. THE COUNTIES OF

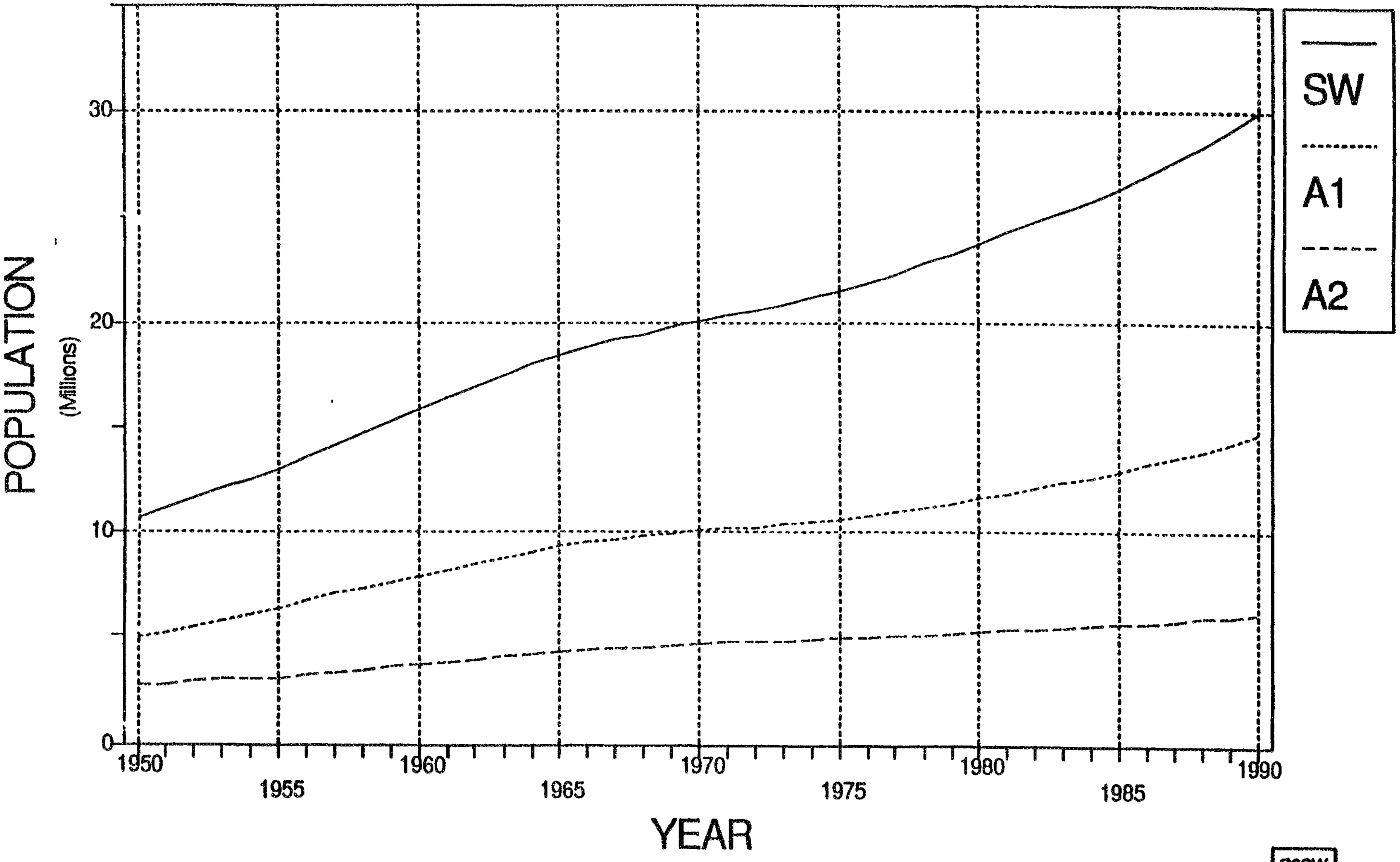
Los Angeles
Orange
Riverside
San Bernardino
Ventura

AREA 2 IS THE BAY AREA. THE COUNTIES OF

Alameda
Contra Costa
Marin
Napa
San Francisco
San Mateo
Santa Clara
Solano
Sonoma

POPULATION

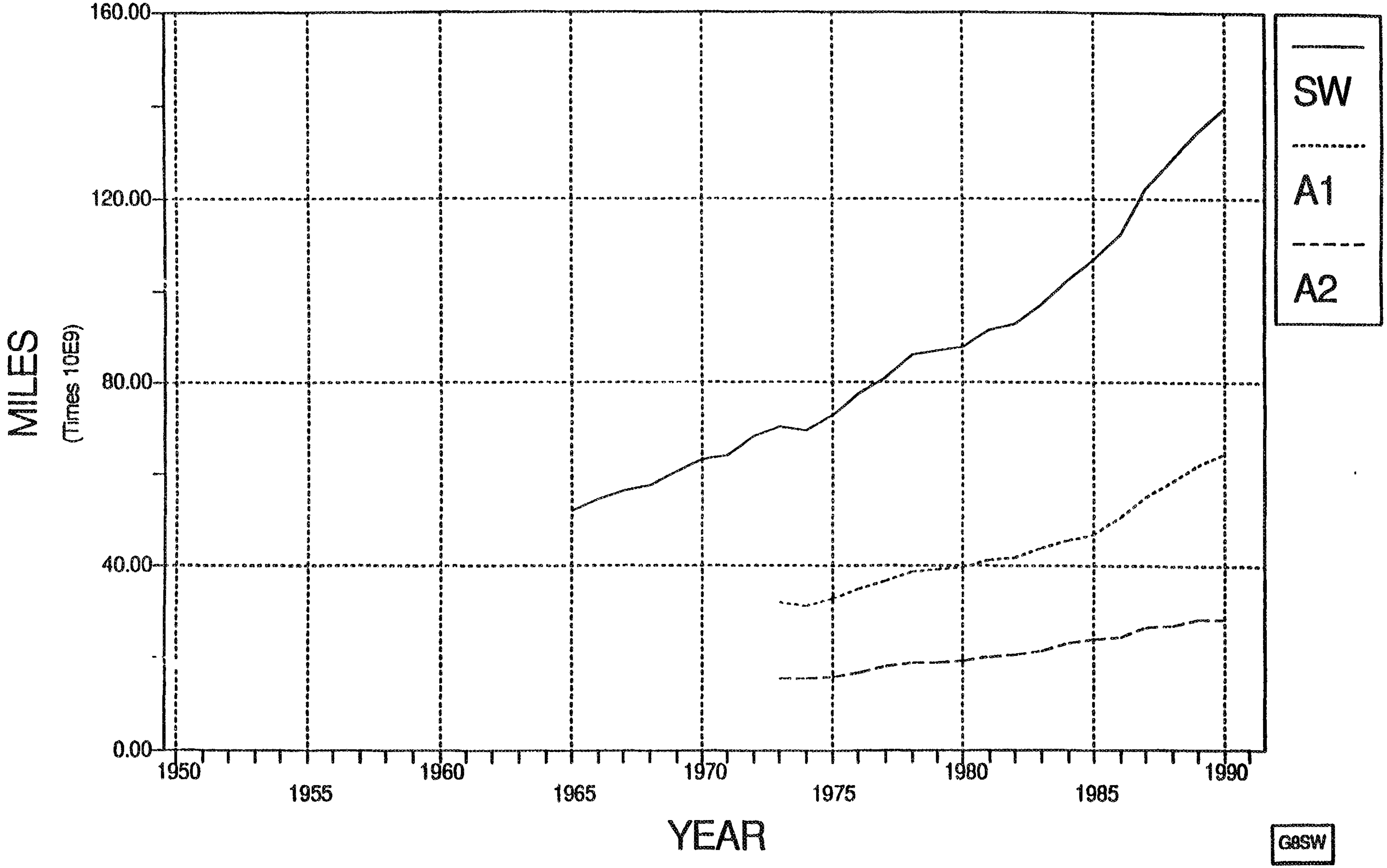
STATEWIDE VS. AREA 1 VS. AREA 2



G3SW

VEHICLE MILES TRAVELED

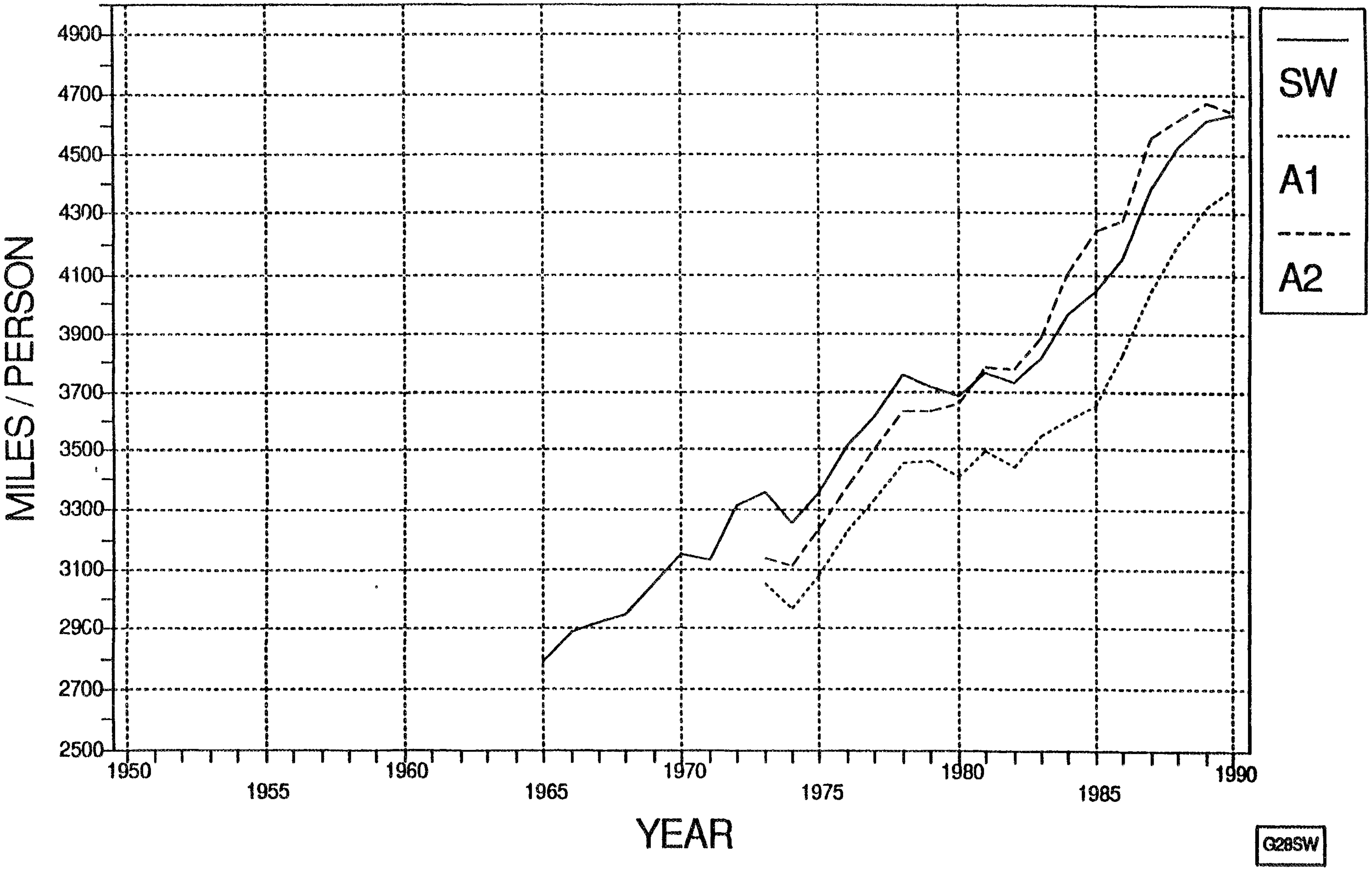
STATEWIDE VS. AREA 1 VS. AREA 2



G8SW

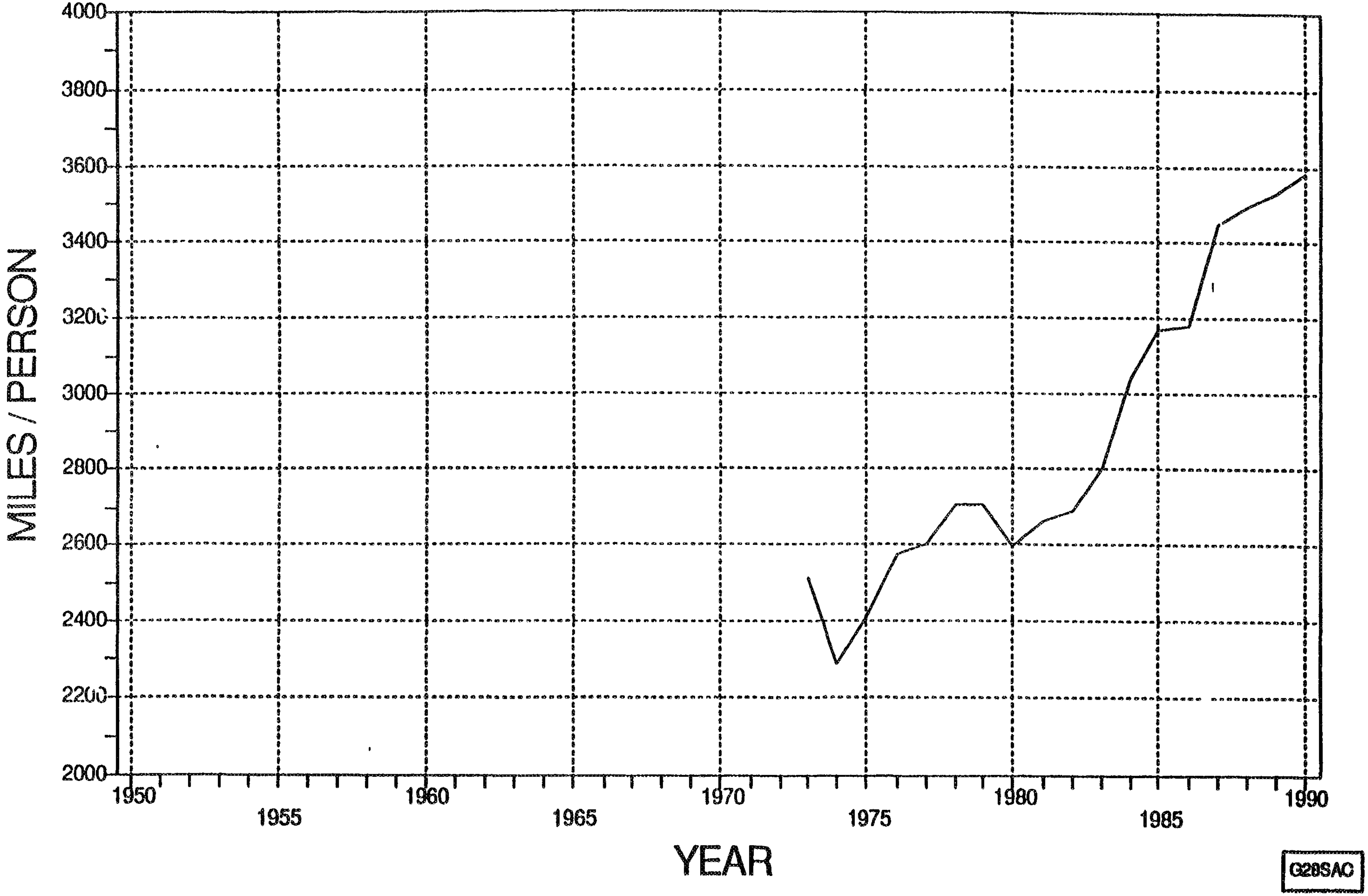
VEHICLE MILES TRAVELED / POPULATION

STATEWIDE VS. AREA1 VS. AREA 2



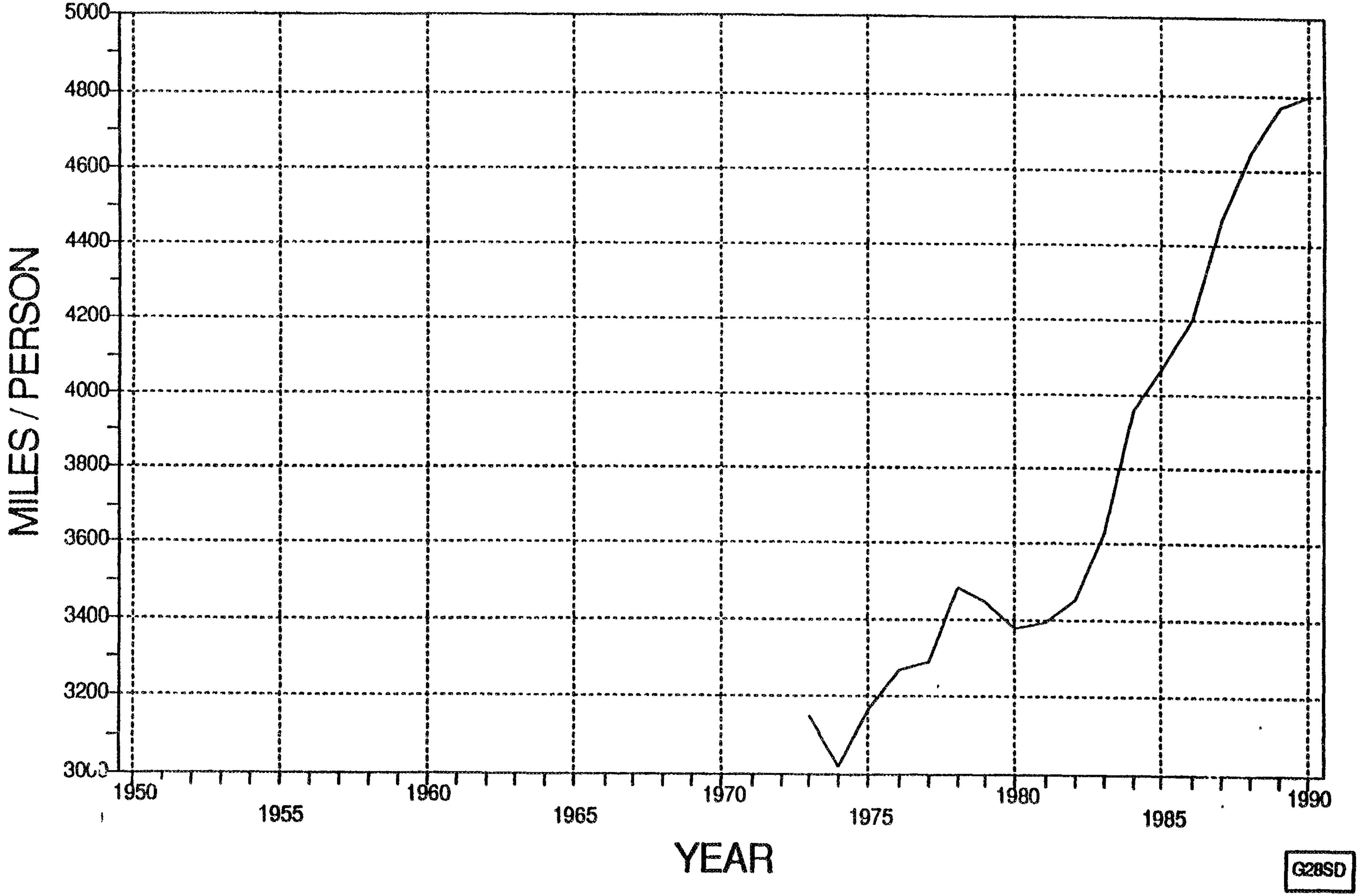
G28SW

VEHICLE MILES TRAVELED / POPULATION
SACRAMENTO COUNTY



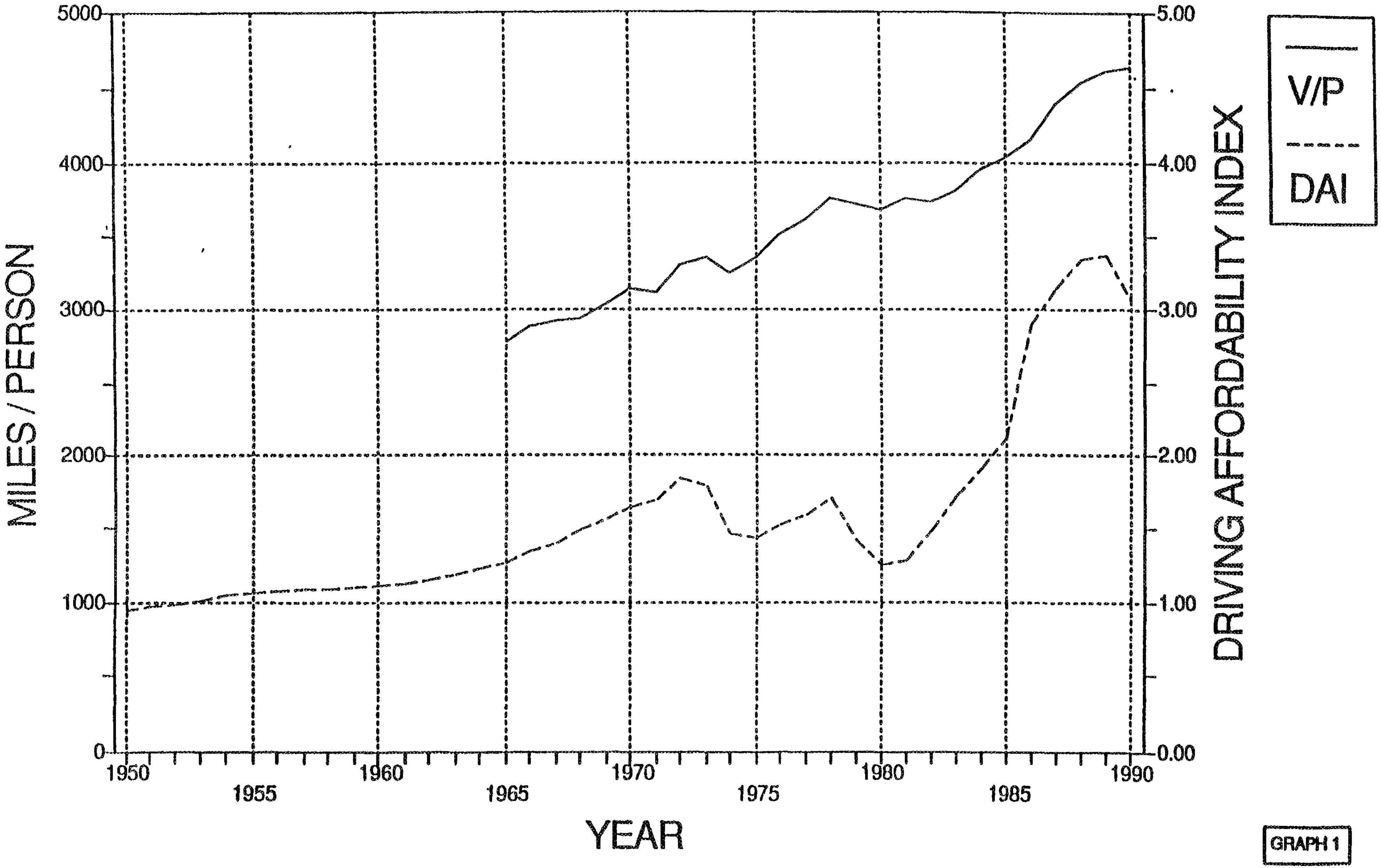
G28SAC

VEHICLE MILES TRAVELED / POPULATION
SAN DIEGO COUNTY



G28SD

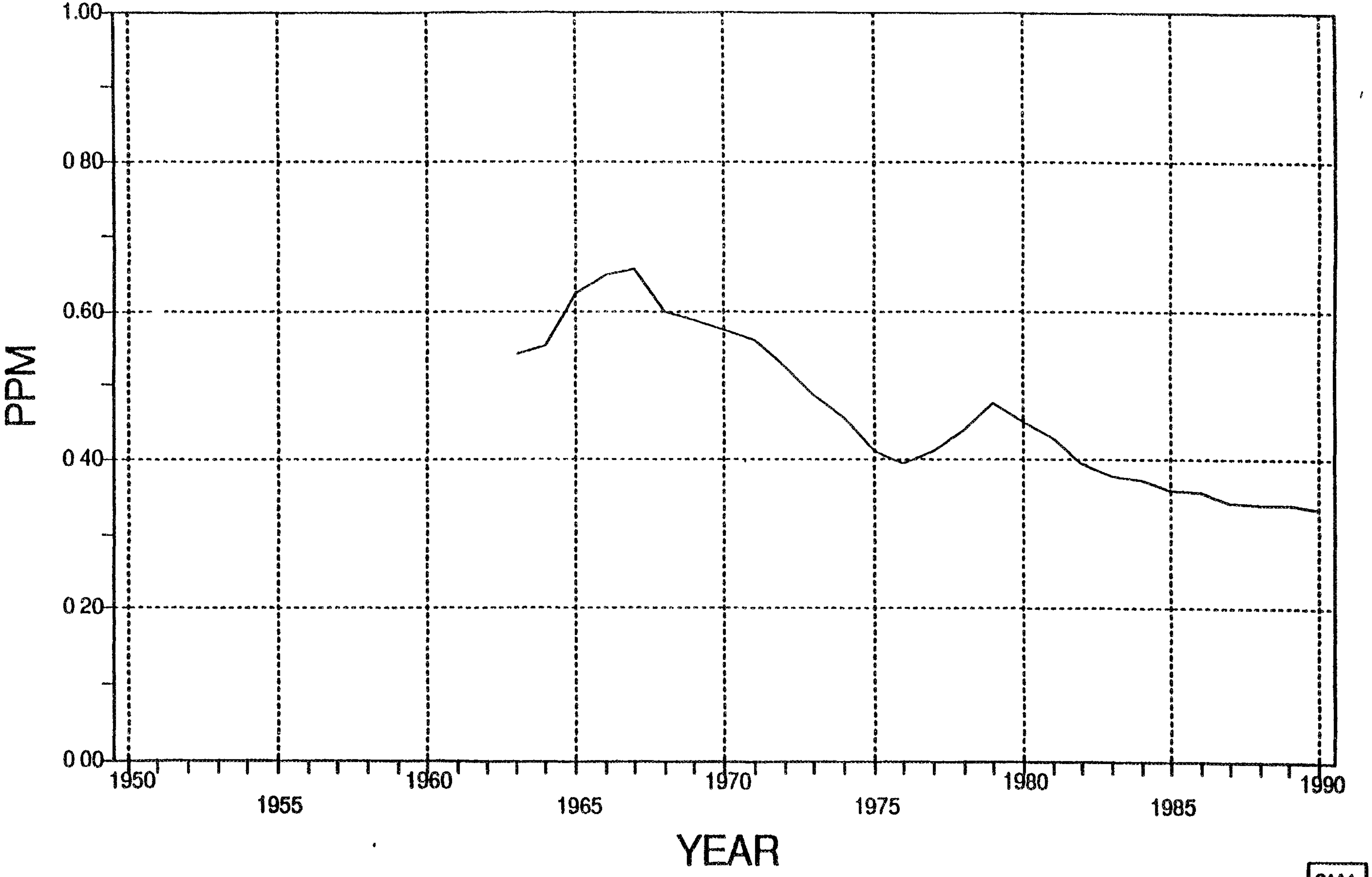
VMT / POPULATION VS. D.A.INDEX (C)
STATEWIDE



GRAPH 1

3-YEAR AVG. PEAK O3 CONCENTRATIONS

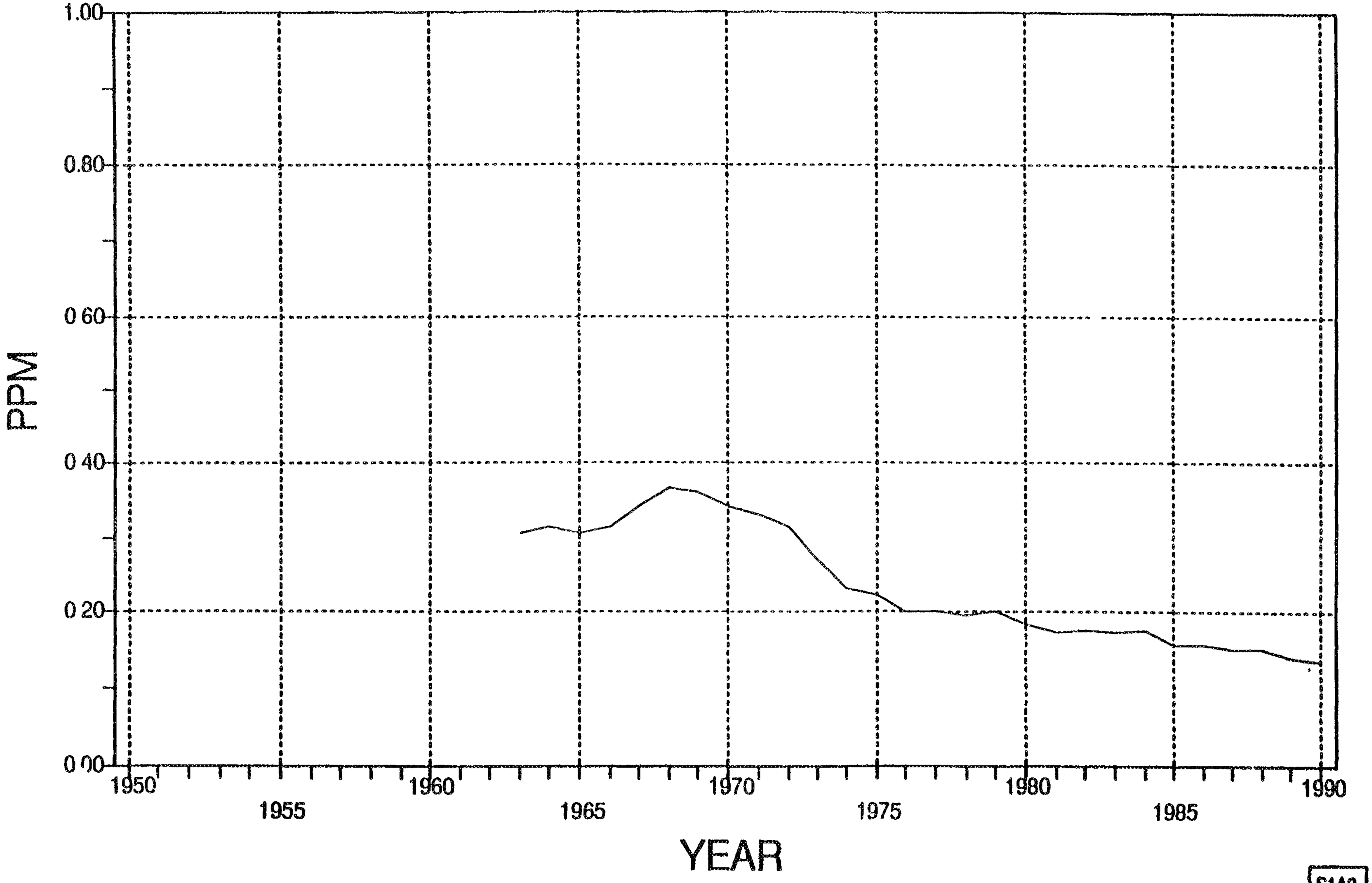
AREA 1



S1A1

3-YEAR AVG. PEAK O3 CONCENTRATIONS

AREA 2



S1A2

STATE OF CALIFORNIA

OFFICE MEMO
Std. 100

DATE: 6-28-93

TO:

STEVE BORROUM
OPPD

FROM:

NORM ROY
OTI

PHONE: 5-6798

Subject: UC Berkeley Induced Growth Study

Per your request, I've reviewed the draft report and have the following comments:

- The study deals with improved state highway segments only and ignore the impacts on non-state highways (see page 3-1, footnote). Increases in traffic on a freeway segment most likely was diverted from "parallel" non-freeway facilities, rather than new travel.
- On page 3-2, the authors acknowledge that the study is "limited in several respects". Clearly, without a total corridor analysis, i.e., state and non-state highways, conclusions about induced growth are not valid.
- Same problem with the areawide analysis in chapter 6. Without the non-state highway impacts, no reasonable conclusion can be made about overall congestion and emission impacts.

In addition, attached are Chuck Chenu's comments on this study.

Attachment

Review of the report - Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Impacts prepared by UC ITS

I do not see anything substantive in the report. Totally new traffic (purely new traffic "induced" by the construction). Conclusions are very suspect.

Specific comments include:

3/all Both the traffic level and traffic growth models developed by ITS use data from the Count Book and as therefore the values derived include BOTH induced (if any) and diverted traffic. The report uses the term "induced" which is misleading.

Some assumptions made in the model development and application are suspect at best.:

18 sites in various areas - north & south
Three year count cycle
Counts at 1-4-7-10 yr before / after project
Uniform directional factor of 0.66
Uniform 2300 vplh capacity

4/all The freeway - corridor land use development model is very complex (perhaps overly so and contains some 20 to 25 variables). Perhaps a good academic exercise. It was developed with data from eight corridors.

Conclusions reached include that capacity enhancements (added capacity projects) have a significant effect on residential and commercial building permits; no effect was detected on industrial development.

I think that this relationship is secondary with both the addition of capacity and the number of building permits related to an independent factor or policy decision.

6/all Analysis of data from fifteen regions indicate such things as that there is a strong relationship between VMT, Lane Miles and Population. These relationships are seen at the county level and are even stronger at the regional level.

This analysis also indicates that the relationship between VMT and the Price of Gas is very weak.

INFORMAL FORM 100

TO: Steve Borroum, OPPD

FROM: Greg King, ED DATE: July 1, 1993

RE. UC-Berkeley Highway Capacity Study

Per your request for a review of the above-referenced draft, I am submitting comments jointly made by Bob Clark and myself.

The study establishes a framework for analyzing some of the critical aspects related to land use development and transportation. Because the study findings may have increasingly important policy implications vis-a-vis the issue of growth (or traffic inducement, as the consultants may prefer), we feel it is important that this study should be critiqued by others outside Caltrans, including academic circles and possibly FHWA's Office of Environmental Policy. This is especially true since the draft study seems to deviate considerably from those that went before it. The authors suggest reasons why this is so-- but naturally clinging to the notion that theirs offers the most correct methodological approach and analysis. Personally, I wonder whether they are correct to stretch the historical traffic data they have used for purposes other than for what it was intended. And your point about some of the cause and effect relationships being rather tenuous is well taken. So what is the next step?

Thought might be given to hiring academic reviewers under a Personal Services contract. These could include experts such as Genevieve Giuliano and Peter Gordon (USC), Martin Wachs (UCLA), Melvin Webber and Elizabeth Deakin (UCB), to name five in California who have established credibility in related transportation research areas.

In the case of Giuliano in particular, our feeling is that she could probably make a very good contribution in assessing the UCB study based upon seeing some of her thoughts expressed on the topic. Her opinion is that new or induced growth would occur only when the construction project significantly increases the propensity for economic growth in the region, so it would be interesting to have her take a look at the methodological assumptions of the UCB consultants who conclude that "roads generate traffic."

A second option you might consider would be to organize a forum or round table seminar with these academicians to discuss the report in a refereed moderator format. The advantages to these approaches, of course, is that it may relieve some of the burden from Caltrans in reconciling those findings of the UCB report in which we are not in agreement.

The authors should consider incorporating a discussion of VMT in light of the views expressed by Charles Lave in "Things Won't Get a Lot Worse: The Future of U.S. Traffic Congestion," a published working paper from the UC Transportation Center (1991). Lave argues that the growth of VMT is reaching an asymptote and we have essentially seen the zenith of congestion. Therefore, the deep concern over long-term adverse effects when new capacity reaches saturation could become a moot point.

Given the sizable increases in VMT in California, well over and above population jumps as well as capacity increases, the study does not take into account the influence of expanded car ownership and increased economic activity on the volume of traffic. Too, though the study looks at job growth in the various case study cities, the majority of vehicle trips generated in recent trends are more often non-work related.

Regarding the personal surveys, though human perceptions are known to change over time, the fact that so consistently developers and community planners downplayed the role of transportation facility expansion as a major influence versus quality of life factors and housing prices, should not be totally dismissed.