

UC Berkeley

Earlier Faculty Research

Title

Effects of Land Use Intensification and Auto Pricing Policies on Regional Travel, Emissions, and Fuel Use

Permalink

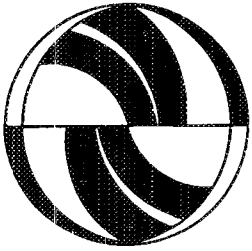
<https://escholarship.org/uc/item/2hg581pb>

Authors

Johnston, Robert A.
Ceerla, Raju

Publication Date

1995



**Effects of Land Use Intensification and
Auto Pricing Policies on Regional Travel,
Emissions, and Fuel Use**

Robert A. Johnston
Raju Ceerla

Working Paper
UCTC No. 269

**The University of California
Transportation Center**
University of California
Berkeley, CA 94720

**The University of California
Transportation Center**

The University of California Transportation Center (UCTC) is one of ten regional units mandated by Congress and established in Fall 1988 to support research, education, and training in surface transportation. The UC Center serves federal Region IX and is supported by matching grants from the U.S. Department of Transportation, the California Department of Transportation (Caltrans), and the University.

Based on the Berkeley Campus, UCTC draws upon existing capabilities and resources of the Institutes of Transportation Studies at Berkeley, Davis, Irvine, and Los Angeles; the Institute of Urban and Regional Development at Berkeley; and several academic departments at the Berkeley, Davis, Irvine, and Los Angeles campuses. Faculty and students on other University of California campuses may participate in

Center activities. Researchers at other universities within the region also have opportunities to collaborate with UC faculty on selected studies.

UCTC's educational and research programs are focused on strategic planning for improving metropolitan accessibility, with emphasis on the special conditions in Region IX. Particular attention is directed to strategies for using transportation as an instrument of economic development, while also accommodating to the region's persistent expansion and while maintaining and enhancing the quality of life there.

The Center distributes reports on its research in working papers, monographs, and in reprints of published articles. It also publishes *Access*, a magazine presenting summaries of selected studies. For a list of publications in print, write to the address below.



**University of California
Transportation Center**

108 Naval Architecture Building
Berkeley, California 94720
Tel: 510/643-7378
FAX: 510/643-5456

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation.

**Effects of Land Use Intensification and Auto Pricing Policies
on Regional Travel, Emissions, and Fuel Use**

Robert A. Johnston
Raju Ceerla

Division of Environmental Studies
University of California at Davis
Davis, CA 95616

Working Paper
1995

UCTC No. 269

The University of California Transportation Center
University of California at Berkeley

ABSTRACT:

In this paper, we simulate the effects of policies intended to reduce auto travel, emissions, and fuel use. We review previous studies of auto pricing and land use policies, both the empirical research and simulation studies. We then describe our methods for modeling the Sacramento, California, region, which include the use of a four-step travel demand model and the California emissions models. We find that: 1. land use intensification near to passenger rail stations, 2. strong parking, fuel, and all-day roadway pricing policies, and 3. rail transit expansion together may be able to reduce travel by 10%, fuel use by 14%, and emissions by 8-14% in 20 years. We interpret our findings in terms of the earlier studies and discuss the limitations of our models. Finally, we suggest improvements in modeling to better simulate the effects of these policies.

INTRODUCTION

It is claimed that many metropolitan regions in the U.S. will not be able to meet the federal Clean Air Act requirements for emissions reductions unless they can substantially reduce travel (U.S. Office of Technology Assessment, 1988). Improved "smog" inspection procedures and cleaner engines will not be adequate to meet the new standards in many urban regions, given present technologies and the short timelines in the Act.

Several types of modest travel demand management (TDM) measures are being deployed throughout the nation. Generally speaking, these measures will reduce vehicle miles travelled (VMT) by only a few percent over ten years, which will not keep up with growth in VMT in most regions (for example, see Bay Area, 1991; Bae, 1993). There are, however, two types of TDMs, largely untried in the U.S., that offer the possibility of larger reductions in trips and VMT: travel pricing measures and land use measures that support transit, walking, and biking.

BACKGROUND

Many general overviews of transportation demand predict increased travel in developed countries in the future, due to higher incomes allowing increased levels of activity per person. These researchers also predict a continuation of the shift to more energy-intensive modes. Even though each mode is becoming less energy-intensive, due to technological improvements, the increases in VMT and the switch to autos and airplanes for passengers and to trucks for freight is causing an increase in energy use in transportation per capita (Schipper and Meyers 1991). Vehicle growth exceeds population growth, especially in developing nations, and these nations will contribute much greater shares of pollutants and greenhouse gases in the future (Walsh, 1991).

In the U.S., the fact that travel costs have gone down, especially out-of-pocket costs, has increased travel, even in recent years when per worker incomes have fallen slightly. Shelter costs have risen as a proportion of income and so households have traded longer commutes for cheaper housing in the suburbs. In addition, basic employment is no longer dependent on rail facilities and so is also decentralizing.

All of these trends have caused concern, and attention recently has focused on travel demand management (TDM) measures. The federal Clean Air Act requires substantial reductions in mobile emissions in many urban regions. The act also requires the adoption of all feasible TDM measures.

LITERATURE REVIEW

A. Land Use Policies

The two main types of land use measures for TDM are jobs-housing balance and density increases near to transit facilities.

The general opinion is that jobs-housing balance (land use mix) will not reduce motorized trips and VMT much, because theoretically one expects workers to search for jobs within a certain (say, 30-minute) commute radius, not a shorter one, and therefore they end up with 25-minute average commutes, because the bulk of the jobs are in the outer area of their circular search pattern.

A comparative study using models from several urban regions in developed countries to test the same TDM policies found that jobs-housing balance alone reduced VMT by only a few percent, because of this phenomenon (Webster, Bly, and Paulley, 1988). A Southern California agency simulated a regional jobs-housing balance policy and found that it could reduce VMT by 11% and vehicle hours of delay (VHD) by 63% over 20 years, however (SCAG, 1988a). Unfortunately, the modeling was apparently done incorrectly, without the feedback of assigned travel times to the trip distribution modeling step (SCAG, 1988b), and one would expect this to cause the overprojection of changes in VMT and especially in VHD. Moreover, research by Giuliano and Small showed that actual commute distances in Southern California were shorter for workers who worked in areas with poor jobs-housing balances (Giuliano, 1992). So the large reduction in VMT found by SCAG probably is largely an artifact of the model or of its operation.

Analysis of San Francisco Bay Area data for selected suburban work zones showed that the availability of housing in a workplace zone slightly decreased commute travel distance and increased the share of commute trips by walk and bike. However, analysis of the same data for the entire region at the district level showed no relation between jobs-housing ratio

in the district of travellers' residences and total daily VMT per capita (Harvey and Deakin, 1990). A simulation by a Bay Area agency showed that increasing jobs-housing balance in areas near to transit stations decreased emissions per capita slightly (projections corrected by us for identical regional population totals). The scenario also increased densities in these areas and so the effects of the two policies cannot be separated (MTC, 1990c; ABAG 1990).

An empirical study in Toronto found that an increase in residential units in the downtown reduced commute trips to the center by 240 trips per workday per 100 units built (Nowlan and Stewart, 1991). The infill residential developments from 1975 to 1988 reduced one-way peak-hour demand by about 3,000 auto trips and by about 7,800 transit trips, thereby saving considerable public monies that would have been needed for expanding transport supply.

An empirical study in the San Diego region found that jobs-housing balance at the zone of residence correlated with shorter commute trips (explained 3.3% of variation) (SANDAG, 1991).

Our interpretation of this evidence is that jobs-housing balance may help under future very congested conditions for roadways, if densities are sufficient to permit walking and biking and are clustered near to good quality transit services. One must remember, however, that if regions increase rail transit availability (urban and commuter rail), workers can live farther away from their jobs (Wachs, 1989).

We note here that standard regional travel models typically have no accessibility variables in the trip generation and trip distribution steps and do not represent nonmotorized modes (walk and bike) at all, and so underrepresent the effects of land use TDM policies. The total effect of these limitations is unclear.

The evidence is much more positive and complete concerning density increase as a TDM. An international literature review found that there was some consensus that a system of many medium-sized cities with moderate densities or linear cities with moderately high densities would use less energy in transportation (Cope, Hills, and James, 1984). A recent review of cross-sectional data from 32 cities from around the world showed that higher densities greatly reduced VMT per capita (Newman and Kenworthy, 1989). That study has been disputed on the basis of the quality of both the travel data and the definitions of the

regions' boundaries.

An analysis of metropolitan land use data in the U.S. showed that population level increased gasoline consumption, when density and clustering were controlled for (Keyes, 1982). That study also found, however, that relatively high densities and relatively high levels of clustering reduced gasoline consumption, whereas a concentration of jobs in the urban center increased consumption, presumably due to longer commutes. The author showed the need to carefully specify the measures of density and clustering that are used in the analyses (generally regression models).

A recent international study used urban transportation and land use models from several urban areas to simulate the effects of a set of TDM policies and found a fairly good consensus that higher residential densities reduce VMT per capita. Land use policies, however, were found to be hardly effective unless accompanied by travel pricing policies and improved transit and walking/biking facilities. Reducing sprawl at the edge with urban growth boundaries also was found to reduce VMT, in conjunction with pricing and transit improvements (Webster, Bly, and Paulley, 1988).

A recent report by the California Air Resources Board reviewed the literature showing that higher residential and employment densities, especially if located near to rail stations, generate higher mode shares for transit and cited Toronto as an example of good land use planning, with its policies for infill development, density increases near to rail stations, and jobs-housing balance, including in the urban center (California ARB, 1993). The Board staff estimates possible regional VMT reductions of 4-11% as a result of land use changes and an additional 5-10% from improved transit and ridesharing.

Several regional simulations of density policies have been done in the U.S. and they agree that such policies are effective, to some degree. A study of the Seattle region found that the concentration of growth into several major centers would reduce VMT about 4% over 30 years, but there was no clear winning scenario in terms of emissions, even including a dispersed growth scenario. It appeared that the concentration of travel in the centers left the peripheral areas less congested and so people travelled farther in these areas (Watterson, 1991). This study is noteworthy because the travel models were run properly equilibrated and land use models were also run, so that travel-land use interactions were captured. We

note that a tighter urban growth boundary might have reduced VMT and emissions slightly more in the growth centers scenario, especially if road expansions were limited in the outer areas.

A simulation in Montgomery County, Maryland, showed that density increases near to rail stations and bus lines, combined with auto pricing policies and the expansion of passenger rail service, would reduce single-occupant commute trips substantially (Replogle, 1990). The modeling was sophisticated, using land use variables in the equations for peaking factors and for mode choice.

A 20-year simulation in the Portland, Oregon, region found that substantial increases in densities near to light rail stations and to feeder and express bus lines, combined with free transit, both within only the western quadrant of the region, would reduce regionwide VMT by 14%, while leaving VHD unchanged, when compared to a scenario with an outer circumferential freeway (Cambridge, 1992). These models included walk and bike modes and included land use variables in an auto ownership step.

A review of several regional simulation studies in the U.S. found that higher densities near transit would reduce auto travel and energy consumption about 20% over 20 years. The Washington D.C. regional study reviewed found that sprawled growth could use twice as much energy in travel as would dense centers with good transit service. Wedges and corridors, a less drastic scenario, reduced travel energy use by 16% (Keyes, 1976).

Another review of simulation studies in the U.S. concluded that higher density near transit lines could reduce travel by up to 20% regionally (Sewell and Foster, 1980). A review of studies in several countries found that improved transit service could reduce auto ownership by 5-10% and that households with fewer autos had lower VMT (Colman, et al., 1991).

An empirical study of five San Francisco Bay Area communities found that doubling residential density reduced VMT per household and per capita 20-30%, and this finding was corroborated with data from other urban regions around the world (Natural Resources, 1991). A simulation in the Bay Area found that increasing residential density and jobs-housing balance near to passenger rail stations produced slightly lower levels of emissions per capita (calculated by us) and lower emissions in areas adjacent to the region. No feedback of

assigned travel times to trip distribution was done, and so the results may be biased slightly (MTC, 1990b, ABAG 1990).

An analysis of Bay Area data showed that increased residential density decreased VMT per capita. Unfortunately, the densest areas also were served by rapid rail transit and so the two effects cannot be disentangled. Looking only at the districts with such transit service, however, still shows a strong relationship between density and VMT. Also, looking at the districts with poor transit service shows this same slope, but more weakly (Harvey and Deakin, 1990).

To conclude regarding land use policies, jobs-housing balance (land use mix) seems to not be very effective, unless as part of a density policy. Density increases near to transit lines seem to be effective in reducing VMT and emissions and energy use, especially in conjunction with travel pricing, not building more freeways, and major improvements to transit, especially exclusive guideway transit.

B. Pricing Policies

An international comparison performed with travel and land use models testing the same TDM policies found in general that auto costs had to rise by 300% to reduce VMT by about 33% (Webster, Bly, and Paulley, 1988). If accompanied by density increases near transit, better transit speeds, and worse auto travel speeds, pricing was found to be much more effective. Since the work trip is so unresponsive to price increases (demand is inelastic), good transit service to work centers was found to be needed. It was also found that large parking charges must be regionwide or, better yet, nationwide, to deter firms and households from moving from existing employment centers to the suburbs or from one urban region to another. Increasing auto operation costs per se was found to increase transit travel to work in the various regions, especially if good radial service (to the urban center) was simulated. This policy also increased walking to local retail centers. Increasing auto purchase costs was also found to work well, as autos seem to be used for about the same amount of VMT annually in various countries, regardless of household incomes and location (Webster, Bly, and Paulley, 1988).

Road and travel pricing have been advocated by economists for decades. One recent

review of the literature shows the large welfare savings possible from road charges, but concludes that these policies are infeasible politically and so recommends efficient levels of parking pricing, efficient truck weight fees, transit subsidies, and bus-only and carpool lanes (Morrison, 1986). Another recent review finds that congestion is not inefficient and that economic efficiency requires carpool or bus-only lanes to speed up local and express bus transit, more rail transit, and toll roads as well as free roads, all in order to improve competition among modes (Starkie, 1986). We do not address whether transit operators can increase service fast enough to meet the large demand increases that would occur if significant road pricing were used. Regions will have to adopt road pricing gradually and also make many transit improvements up front, that is before the road pricing takes effect. The travel pricing demonstration projects being started in the U.S. recognize this problem.

A comprehensive review of congestion charging mechanisms for roadways found that indirect charges, such as parking charges, fuel taxes, area licensing, and vehicle purchase and license taxes are not economically efficient in reducing congestion and travel costs. Peak-period road pricing was recommended, supplemented by parking taxes. Automatic vehicle identification (AVI) was found to make tolling in-motion less costly than tollbooths (Hau, 1992). Another recent analysis also recommends peak-period road pricing and parking pricing, to relieve congestion (Downs, 1992). The above studies (Morrison, Starkie, Hau, Downs) were conceptual economic evaluations accompanied by limited empirical evidence and have to be carefully interpreted for the purposes of reducing travel, emissions, and energy use, since their objective is usually economic efficiency.

A review of congestion charges in Europe (Jones, 1992) states that roadway and downtown cordon tolls are being investigated in Greece, Sweden, the U.K., and the Netherlands. One conclusion of interest is that peak-period road tolls are more likely to spread peaks and suppress trips than to cause a switch in mode in low-density urban regions with poor transit service. If densities are high, good transit service is available, and road charges are high, mode switching was predicted to be the prevalent response. Carpooling would rise only when pools are exempted from tolls. Support for tolls would increase substantially if the avowed purposes of the tolls were to include safety and environmental quality. This analysis was mainly conceptual.

Mogridge (1986) issued a proviso for very large cities with well-developed transit systems. He argued that tolling road travel or parking would not reduce auto travel much, because of unmet demand for auto travel by transit users. Charging autos would simply shift wealthier travellers to auto and less-wealthy ones to transit, and mode shares and speeds would not significantly change. This equilibrium situation only exists where transit travel times are roughly equal to auto travel times, a situation that occurs only in very large urban areas. Mogridge was arguing from modeling experience in London.

Empirical studies show that the effects of pricing auto travel vary greatly according to the quality of the alternative modes available and the nature of the charging scheme. May (1992) reviewed the evidence, which includes the Singapore downtown a.m. cordon charge of \$2.50, which reduced morning downtown-bound traffic about 44%, and the Bergen, Oslo, and Trondheim toll rings, which charge from \$0.80 to \$1.60 per trip all day and reduced traffic only a few percent.

A simulation of area pricing for downtown London projected a 45% decrease in traffic with a \$2.50 charge (May, 1992). An interesting finding of another London simulation study showed that expanding commuter rail itself would not reduce auto commuting significantly, while road pricing together with rail improvements could reduce auto commuting by up to 20% and even 30%, if rail fares were reduced (May, 1992).

A simulation of auto pricing policies in Southern California found that VMT could be reduced by about 12% and pollutants by about 20% with a peak-period road congestion charge of \$0.15/mi., employee parking charges of \$3/day, retail and office parking charges of \$0.60/hr., emissions fees averaging \$110/year/vehicle, and deregulated (cheaper, better) transit services (which accounted for about 2 percentage points of the reductions) (Cameron, 1991). A rather good set of travel demand models was used for this evaluation.

Empirical studies of large employer sites show 20-30% reductions in commute trips to the sites, when employees pay fully for their parking (Willson and Shoup, 1990). Shoup (1992) argues that eliminating employee parking subsidies will create growth in urban centers and other employment centers, increase infill development on small, "leftover" parcels, and reduce transit ridership peaks. All of these changes would increase the efficiency of transit and transportation in general.

A regionwide simulation in the Bay Area found that eliminating parking subsidies to workers would reduce commute trips 25-50%, with the high values in the most dense centers (MTC, 1990b). Another Bay Area study showed that pricing measures could reduce VMT by 15% in 5 years. The policies were parking charges as per the Southern California study, smog fees averaging \$125/year/vehicle, a fuel tax of \$2/gal., and unspecified congestion pricing (MTC, 1990).

The conclusion regarding pricing is that it is effective, except in very large urban areas with excellent transit service, where pricing auto use at peak periods per se may not reduce VMT, due to pent-up demand for auto travel. The spending of the toll revenues on transit improvements, however, (not considered by Mogridge) could reduce VMT and emissions, by making transit more competitive. Pricing measures must be accompanied by substantial improvements in transit service, to be effective.

C. Conclusions Regarding Land Use and Pricing Policies:

In terms of identifying potentially useful policies, these studies indicate that generally:

1. density per se is more important than land use mix per se,
2. density near to transit seems to be even more effective,
3. mix (jobs-housing balance) can be effective only if nonauto modes are available (walk, bike, transit),
4. auto pricing greatly improves the effectiveness of density and mix policies,
5. distance-based road pricing may be needed to reduce travel on the edges of urban regions,
6. auto pricing (travel, parking, fuels, emissions) is ineffective in most regions unless accompanied by transit improvements and density increases near to transit,
7. vehicle purchase taxes can be effective,
8. parking charges can be effective, and
9. downtown cordon charges can be effective.

In terms of travel pricing, we consider only peak-period and all-day road pricing in this study, not downtown cordon charges. Relying on previous studies, we expect that peak-period road charges would reduce peak-period travel and congestion, and could reduce

ozone precursor emissions (NOX, ROG) and energy consumption. In cases of high congestion, however, tolls could increase travel by increasing throughput at, say, speeds of 30-40 mph. We would expect CO hotspots to be reduced, depending on local situations. Cordon charges, levied upon entering the downtown, would be more effective in reducing CO. Such charges are being studied by large European cities. We do not consider cordon pricing, because of its poor reception in the U.S. and because very high-quality transit service is needed to make it effective. Perhaps it could follow the policies we consider here.

We do not consider the equity effects of tolls in this phase of our research. We note, however, that several studies have shown that tolls can benefit all income groups (Small, 1983; Small, Winston, and Evans, 1989). A recent paper develops a program for spending the revenues that would be generated by the Southern California pricing policies suggested by Cameron (1991) and shows that all commuters would benefit financially, due to posited tax rebates and transit improvements (Small, 1992).

We cannot simulate vehicle purchase taxes or annual registration and emission fees with the present model set. We do test parking pricing, however, since it has been found effective and we test a fuel tax.

By way of integrating the discussions of pricing and land use measures, we note that cold starts account for the majority of mobile hydrocarbon and CO emissions in most large urban areas and so the short trip should be a focus of TDMs. Improved transit provision and peak-period auto pricing may reduce work trips, if land uses are concentrated around transit lines. Parking pricing can be very effective as a TDM, especially if transit service is adequate to meet demand. Nonwork trips can be shifted from the auto to walk, bike, or transit, if land use mix and density are sufficient, sidewalks and bike lanes are provided, and if adequate transit service is provided. Only exclusive guideway transit (rail, busway) can compete favorably with autos in most urban regions.

Controlling growth at the edge of the urban region may not be very effective as a TDM measure, according to one set of studies reviewed. We think that all-day (distance-based) travel pricing may make this policy effective, however.

We conclude that all of these policies should be simulated in an attempt to project changes in VMT, emissions, and energy consumption. We test policies separately and

together, since the studies show the need for mutual reinforcement among increased density and mix near transit, improved transit service, and auto pricing. The following evaluation should be viewed as heuristic, not determining. Also, we do not consider political feasibility. Simulation studies, as well as empirical ones, can affect politics and so in the long run, we may not have to be bound by present attitudes.

METHODS

A. The Travel Demand Modeling

1. Description of the Modeled Area:

The study area was that of the Sacramento Regional Transit (RT) Systems Planning Study of 1990. All Base Year freeway and highway system characteristics represent conditions existing for the year 1989. The No-build 2010 alternative represents the land use growth after 1989 without any new major transportation facilities.

2. Network Characteristics :

No changes were made to the 1990 Systems Planning Study transit network. The transit network developed was based on conditions and lines existing for the year 1989 (Base Year). The transit network included transit lines operated by agencies other than Sacramento RT and also included separate a.m. peak period and off-peak period transit networks (Parsons, 1990). This was done for the purpose of proper mode split during the peak and non-peak periods. Zonal walk-to-transit accessibility measures were also included in the Systems Planning Study.

3. Land Use and Socioeconomic Data :

We used the Sacramento Area Council of Governments (SACOG) base year (1989) and projected year (2010) land use files for all runs, except those where we tested land use policies. In those cases, we describe the changes that we made.

4. Trip Generation :

In the Systems Planning Study, the trip generation model was based on the 1968

Sacramento Area Transportation Study that was developed from a 1968 household survey data set. Changes were made to the production rates, based on rates for similar urban regions. Then the trip production rates were recalibrated (though without using any new household trip data) to reflect 1989 land use and travel conditions. A new set of trip attraction rates was estimated based on trip rates in the 1976-1980 statewide travel survey. Commercial trucks are not modeled.

5. Trip Distribution :

The trip distribution process uses the trip production and attraction data developed in the trip generation stage to distribute trips to the 812 zones using a standard gravity model (Comsis, 1991).

The travel impedance matrix is the zone-to-zone travel times calculated in a step prior to trip distribution. It is calculated as the shortest time path for links along a path between any two zones and accumulating the travel time of the links along the path.

The travel impedance matrix was generated initially using free-flow speeds and then a feedback process was employed by us where speeds from assignment were used. Because this protocol departs from the Systems Planning Study methods, the feedback process is explained below. In the RT Systems Planning Study and in our analysis, intrazonal travel times were generated by estimating the average travel time to adjacent traffic analysis zones. Terminal times were added to each zone-to-zone travel time, to represent access time to automobiles.

In the trip distribution model, the friction factors represent the likelihood of travel between zones based upon the impedance (time cost, in this model) between the zones. The friction factors that were used in the Systems Planning Study were based on those used in the Seattle, Washington region, which was assumed to have characteristics similar to those in the Sacramento region. The Seattle friction factors were for daily travel, as the Sacramento model is a daily travel model. Five sets of friction factors were developed, one for each trip purpose. The same friction factors were used for both the 1989 base year and the 2010 future year forecasts.

6. Mode Choice :

New mode choice models were developed for the 1989 Systems Planning Study based on the 1989 RT ridership and on-board surveys. Mode choice models were developed for two sets of trip purposes, home based work trips and non-work trips.

The home based work trip mode choice model is a multinomial logit model that predicts mode shares for: Walk to Transit, Drive to Transit, Drive Alone, 2+ Person Auto, and 3+ Person Auto. Most of the coefficients of the mode choice model were obtained from comparative studies of other models from other large urban areas in the U.S. Insofar as these other models were discrete choice, household-based utility models, such transference is arguably acceptable, theoretically. Midrange values from models of other urban areas were used for the level of service coefficients (Parsons, 1990).

The home based work trip mode choice model is further stratified into car ownership categories. The characteristics of the model were maintained in our modeling processes for the various alternatives. Changes were only made in the auto operating cost estimation process where additional variables to reflect roadway and fuel pricing were introduced.

The nonwork trip mode split estimation process involves factoring applied to the home based work trip transit shares. These factors were applied to each zone-to-zone interchange that has transit service during the offpeak period and were factored for origin-destination distances, auto ownership, and trip purpose.

7. Traffic Assignment :

In the MINUTP systems software, traffic assignment is done by reading trip files, building paths for those trips, assigning the trips to the links in the paths (accumulating link volumes), and when all trips have been processed, adjusting the link travel times based on congestion and repeating the entire process for the specified number of iterations. The number of iterations that had been used in the Systems Planning Study was 5 and this was maintained in our study.

Peak hour modeling is performed using a.m. peak hour directional trip percentages derived from the San Francisco Bay region for each trip purpose and assigning the trips. These travel times are then used for calculating mode choice for all daily work trips.

The mode choice model has been structured to read two sets of travel times, one for single-occupant trips and the other for high-occupancy vehicle (HOV) trips. The model assigns travel time based on capacity constrained peak hour assignment to each occupancy alternative and computes the mode shares, recognizing the HOV time savings.

8. Transit Modeling :

The transit module has the capability to form transit networks, develop zone-to-zone paths along transit networks, extract level-of-service matrices along transit paths, and assign trips to transit paths (Comsis, 1991). The transit network generates sets of transit links that have travel times, distance, a valid mode indicator and parallel links for various modes, transit speeds, and transit time slices for each zone-to-zone path. The bus links are represented by the highway links in the base network, whereas for light rail transit (LRT) separate links are coded. Transit assignment is not capacity constrained.

9. Overall Model Operation Methods:

In the Systems Planning Study, the speeds and travel times were estimated for all peak hour and daily trips in the assignment step. A loop was used to feed these congested speeds and times back into mode choice. This process provided new peak and daily speeds and travel times based on the first estimation. This feedback loop can be repeated for a number of times until the speeds and times do not change significantly (equilibrated values). This partial feedback protocol corrects mode choice for the effects of congestion, but does not correct trip lengths (in the trip distribution step) for these effects. This is a serious flaw when modeling for the purpose of projecting travel and emissions, because trip length is a main determinant of VMT and VMT also determines link speeds. VMT by speed class is a main determinant of emissions.

Therefore, for our modeling we also fed assigned travel times back to the trip distribution step. The assigned peak hour speeds are fed back to the trip distribution step where new origin-destination (O-D) tables are created for work trips. The daily average speeds are fed back to the trip distribution step to recalculate O-D tables for the nonwork trips. Modeling texts agree that such feedback is desirable. The Environmental Protection

Agency adopted regulations at the end of 1993 that require feedback to trip distribution, for air quality conformity analyses done from 1995 on.

10. Our Feedback Procedure Using MINUTP:

The first model run involves the use of uncongested speeds in the trip distribution step, from which a set of O-D tables is estimated for all zone pairs. The new speeds and travel times obtained at the end of the modeling process (after assignment) can be very different from those used at the beginning of the model process. Several iterations need to be done to obtain equilibrated speeds. The feedback process is very computationally time-consuming and thus five iterations are done by us and the average (arithmetic mean) of the five plus the initial run is considered as the equilibrated set of values.

Feedback to mode choice is retained, and so distribution, mode choice, and assignment use the same travel times for work trips and for nonwork trips, respectively. We graphed regional VMT for the six runs of the 2010 No Build scenario, to verify that the output oscillated, due to the negative feedback of VMT on speed. We found that VMT did oscillate in a dampening fashion, as expected. Our runs plotted VMT as a set of converging points, that is the model iterations were leading toward equilibrium. We also inspected the VMT X speed class data that was fed into the emissions models, in order to see if it also followed regular patterns and did not vary wildly. The VMT for the 5-10 mph, 10-15 mph, and 15-20 mph classes varied regularly, inversely to total VMT and dampened. The VMT for the speed classes for 50-55 mph, 55-60 mph, and 60-65 mph varied regularly with total VMT and dampened. Both of these results were as expected. We checked the VMT in these speed classes because emissions per mile are much higher in them than in the intermediate classes and we wanted to verify that our emissions projections were not affected by some artifact of the modeling.

We did not recalibrate the full feedback model, for several reasons. First, the 1989 Base Year VMT fell by only 5%, not a large change compared with typical calibration tests (within 10% for regional VMT and larger ranges for facility types). Second, the model was already calibrated using friction factors for daily travel in Seattle, a larger region with worse congestion. Third, we checked our projected volumes against the base year counts and they

were 96% of the downtown cordon counts. The outer screenline projections were 91% of the counts, in the aggregate. Fourth, adjustment of the friction factors in trip distribution (or even trip generation rates) would not change the rank orderings of our projections. Gravity trip distribution models are not behavioral and so are not policy sensitive or theoretically robust. They are merely phenomenological/descriptive ways of extrapolating past behavior. Fifth, traffic counts in this region, and in most others, are likely to be inaccurate, due to poor sampling.

11. Model Travel Data Outputs:

Model parameters were calculated using the adjusted loaded daily road network. The parameters that were calculated were:

- Total network vehicle miles traveled (VMT)
- Total vehicle hours traveled throughout the network (VHT)
- Vehicle hours of delay on the whole network (VHD)
- Lane miles of congestion (LOS E and LOS F) and
- Average network speed

The model also estimates the person trips by trip purpose and vehicle trips by mode.

12. Strengths and Weaknesses of the Models:

This set of models is representative of those in use in many medium-sized urban regions and so our simulations should be taken to represent what would happen if agencies with similar models performed these tests. The borrowed friction factors and logit coefficients make this model set somewhat abstract, that is not necessarily accurate for this region but, we would argue, useful for policy evaluation in general. There is a logit model for work trips that includes walk access and drive access to transit and the model set was refereed by the federal transit agency under the previous rules for rail alternatives analysis. Other strengths include separate HOV modes and network, which allows us to evaluate HOV scenarios, and small zones in the downtown, which permits fairly accurate estimates of walk-to-transit shares. Also, no K-factors were used in the calibration of the trip distribution step.

On the other hand, many weaknesses require one to treat our projections with care.

The factoring for peak hour trips and the application of those travel times to all work trips probably exaggerates the transit share for work trips and perhaps for all trips. With full feedback, work trips are overshorted and nonwork trips undershorted, but the total effect is unknown. The factoring of nonwork mode shares from the worktrip logit model shares is crude, even though corrected for O-D distance, auto ownership, and trip purpose. There is no auto ownership model and no peak spreading routine. Also, link capacities are approximate and output link speeds not accurate, problems common to past models. The model set was not validated on average speeds by road class. The lack of feedback of assigned speeds, or of any other accessibility measure, to trip generation and auto ownership, even in our "full feedback" runs, leads to the underprojection of VMT reductions due to congestion. The lack of travel cost variables in all the model steps except mode choice leads to the underprojection of the effects of pricing in reducing VMT. There are insufficient demographic variables in trip generation. Age and income affect auto ownership and trip generation, as well as mode choice. There is no land allocation model, and so the effects of major transit and pricing policies in reducing auto travel are underprojected. In addition, there are the problems common to all cross-sectional models.

B. The Policy Alternatives Modeled

1. Pre-Existing (Official) Alternatives:

Several alternatives from the Systems Study were examined in our study and their travel characteristics compared. No changes were made to any input data unless otherwise indicated here. The following are the alternatives that were already developed but were rerun by us with full feedback.

1. 1989 Base Year.
2. 2010 No-Build. Modeled with year 2010 predicted land use data without any major transportation facility improvements. The land use allocations conformed to the federal and state totals projected for the region. The allocations among jurisdictions were determined, however, through political negotiation with the regional agency. The effects of transport improvements on land use patterns was not considered in this process or in the modeling.
3. HOV Lanes. A 93-lane-mile system of existing and proposed new HOV lanes on the

inner freeways by the year 2010 (Figure 1).(Figure 2).

4. Light Rail Transit (LRT). Alternative 8 of the Systems Planning Study (Figure 2).

2. Our Land Use and Pricing TDM Alternatives:

The Transit-Oriented Development (TOD) alternatives and the Pricing alternatives were both based on the LRT alternative. For the TOD alternatives, the land use (housing and employment) and zone characteristics (transit accessibility index) datasets were changed. For the Pricing alternative the zone characteristics (zonal parking costs) dataset was altered. All other zonal input datasets were maintained.

The modeling process for the pricing scenarios was based on three travel cost increases. The auto operating cost was increased by 3 cents a mile to reflect an increase in gasoline taxes of \$2.00 a gallon. Since the long-run elasticity of demand for travel with respect to fuel costs is low, about -0.3, due to a shift to higher-mpg vehicles, we entered a (static, short-term) fuel tax of \$0.60/gallon. This procedure, then, simulates the reduction in fuel consumption due to reduced auto mode choice properly with the (too-high) fleet mpg assumed by the California Air Resources Board, based on lower fuel price assumptions than would occur. Fleet mileage was assumed at 20 miles per gallon and so the per-mile cost increase is 3 cents. In terms of the effects on VMT and the other travel indicators themselves, the fuel tax entered should be seen as \$0.60/gallon.

The congestion pricing was placed at 25 cents per mile for arterials and 50 cents for freeways and applied to home to work trips on all links with failing level-of-service (LOS E and F) to (poorly) approximate peak-period trips. The model is for daily trips and does not directly project peak trips. Parking costs were increased to \$5.00 a day in the downtown, \$3.00 at other major employment centers, and \$2.00 at all other places. Parking costs are entered into the land use zone files, but are read into the mode choice equations, as applied to each O-D pair.

After performing runs with this ambitious pricing scenario, including the peak-period congestion tolls, we found that travel (VMT) increased, because the shift to HOV mode speeded up travel and lengthened trips. The HOV mode also attracted riders from transit. So we defined a second, all-day pricing scheme (applied to all trips) for comparative purposes.

This charge was \$0.30/mile on all roadways. We also included the same parking and fuel charges.

The prices in these two scenarios are near to levels that are economically efficient in large urban areas. Lee (1992), for example, shows that efficient (long run) peak tolls for average U.S. urban highways in urban regions range from \$0.26 to \$0.95/vehicle-mile, while average (peak and nonpeak) tolls would be about \$0.15/vehicle-mile. This figure includes only roadway capital costs. Aschauer (1990, in Decorla-Souza and Kane, 1992) estimated average peak-period costs in the Chicago region at about \$0.41/mile and nonrecovered non-peak costs at about \$0.05/vehicle-mile. Other studies reviewed by them estimate peak-period tolls at \$0.20-\$0.40/vehicle-mile (Decorla-Souza and Kane, 1992). Small (1992) estimates that peak tolls that are efficient in the short run (efficient use) and the long run (efficient capacity) for the Bay Area are \$0.05- \$0.37/vehicle-mile, higher in the central areas.

To those tolls must be added subsidies and external costs, to be economically efficient. A recent unpublished review estimates these costs at about \$0.20/mile (California Energy Commission, 1993). These estimates are much debated and conservative estimates range down to \$0.02/mile (Decorla Souza and Kane, 1992), but the lower-end estimates omit difficult-to-quantify costs, such as defense of oil fields and unreimbursed local road services. All of the studies leave out the effects of excessive auto travel on land use, which increases sprawl, walk times, and urban service costs. Many of these subsidy and external costs are for all travel, not just peak travel.

The transit-oriented development (TOD) alternatives involved the use of the official light rail transit (LRT) network but with considerable changes to the 2010 land use data. Land use intensification was simulated around the existing and proposed light rail stations, as depicted in Figure 2.

All employment and household growth for the year 2010 from the surrounding rural edges was shifted into the TOD zones. About half of the employment growth from the areas adjacent to the corridors was also shifted into the TOD zones. This was done to maintain a reasonable jobs/housing balance in the TOD zones. Two thirds of housing growth from the zones adjacent to the corridors was moved into these zones. Only 25% of the housing growth

in the zones adjacent to the one corridor (Natomas) was shifted to the TOD zones of its corridor. This was done to maintain a reasonable housing density in those TOD zones. Due to the high density of housing and employment along the Roseville corridor only half of the growth in zones adjacent to that corridor were shifted. The shifting of households and employment was done keeping in mind the growth restrictions in some of the TOD zones involving flooding problems and due to the 65-decibel noise boundary around Mather Air Force Base.

A quarter-mile radius was used to identify the TODs surrounding the stations and all land use zones falling mostly within this perimeter were used. The transit accessibility indexes for these zones were converted to 100% to reflect total accessibility of all households and employment to transit. The shifted households were then distributed among the car ownership stratifications to maintain the control totals for each car ownership category and for total trips in the region. Once the housing units and jobs were moved into the TOD zones, they were then shifted between TOD zones along each corridor to maintain reasonable jobs-housing balances and densities.

A total of approximately 70% of single-family housing growth and about 65% of multifamily housing growth were shifted into the TOD zones from the other zones and from within this total approximately 7% of the single-family and 6% of the multifamily housing growth were shifted into the downtown area. Approximately 78% of retail employment growth and 73% of non-retail employment growth were shifted from all other zones to the TOD zones. No retail or non-retail employment were shifted into the downtown area, to improve jobs/housing balance there.

No shifts were made in Davis, because this TOD already was quite dense and the surrounding zones were also dense. For all TOD zones a density cap of around 8 households per acre and 10 retail plus 30 non-retail employees per acre were used as guidelines in shifting the land uses. No changes were made in the special generators and gateway trips that are included in the land use data.

This land use scenario is very ambitious. Intensification near light rail stations, however, has been the cornerstone of the revised Sacramento County land use plan and is also strongly favored by the RT district. A modest intensification scenario was also evaluated by

the regional transportation agency (SACOG) in the late 1980s, but without proper model feedback. Our scenario goes beyond these earlier ones in comprehensiveness (all stations), densities, and jobs/housing balance. In the Portland, Oregon, study of land use intensification, 65% of new residential units and 78% of new employees were moved to their rail station TODs and along feeder and express bus lines (Cambridge, 1992). This intensification was simulated only in one county, which occupies the western quadrant of the region.

C. The Emissions Model

1. Emission Factors:

Mobile emission rates for the region were estimated using the California Air Resources Board's BURDEN and EMFAC7EPSCF2 computer models for calculating airborne emissions (California ARB, 1991, 1992). We used the fleet emission factors for Sacramento County, which comprises about 85% of the fleet in the region. The output from these models was then converted for use in Caltran's PC-DTIM, a travel impact emissions model (Caltrans, 1993).

EMFAC7E produces emission factors for 3 exhaust emission processes and 4 evaporative emission processes. It also produces fuel consumption rates for 13 vehicle class/technology combinations. Emission and fuel consumption rates were estimated for both the base year vehicle models (we used 1990) and for future year (2010) vehicle models.

The following are the emission processes for which the emission factors were estimated.

Exhaust Emission Factors

- Running
- Cold Start
- Hot Start

Evaporative Emission Factors

- Diurnal
- Hot Soak
- Running Losses
- Standing Losses

EMFAC7E calculates emission factors for a range of dew points by default. Dew point was set at 30 degrees F., for conformity with the emissions studies done by the regional

agency. Ranges of speed and temperature can be specified for different emission factor runs depending on the temporal requirement of the transportation model. In our case a temperature range of 62 to 110 degrees F. at 10 degree intervals was selected for the summer inventory. This temperature range also conforms to the emission studies done by SACOG for the run temperature (for running exhaust) and starting temperature (for both hot and cold starts). A speed range of 0 to 65 mph in 5 mph increments was used for emission factor generation. The emission factors generated from EMFAC were then converted for input to PC-DTIM.

2. Direct Travel Impact Model (PC-DTIM):

PC-DTIM calculates air pollutant emission estimates for on-road mobile sources based on detailed information regarding each link (roadway segment) for each hour of the day. Thus this program can be used on the output from most travel demand systems models, such as MINUTP, to generate mobile emissions. In our case the organic air pollutants consisted of Total Organic Gases from Tailpipes (TOG), Evaporative Emissions (EVA), CO, NOX, Exhaust Particulate of Nitrogen (PMEX), and Particulate Matter Due to Tire Wear (PMTW).

3. Transportation Model Outputs for PC-DTIM:

Transportation model outputs could be directly generated from MINUTP models for the PC-DTIM program to calculate daily emissions. PC-DTIM requires a trip table consisting of volumes of trip productions and attractions in both directions and hourly link capacity. It also requires detailed information on the network in terms of link speed, link distance, node coordinates, and facility type. It also requires information on intrazonal volume by trip type, trip end volumes for both attractions and productions by trip type, and the corresponding node coordinates and zones.

Hence the MINUTP model needs to generate an intrazonal file, terminal volume file, and a link description file containing the above information. For each iteration of the feedback to trip distribution these files were generated separately. These separate transportation model files were then used to generate hourly and total daily mobile emission estimates. These separate estimates for 6 runs were then averaged to obtain the converged

mobile emissions. This process was repeated for each alternative.

4. Steps Involved in MINUTP:

1. Person-trips by purpose are converted to person-trips by purpose by vehicle occupancy (Drive alone and Shared Ride).
2. Person trips by purpose by vehicle occupancy are then converted from P/A to O/D format.
3. Person trips by purpose by vehicle occupancy in O/D format are then converted to vehicle-trips.
4. Vehicle trips by purpose by vehicle occupancy which are in separate tables are combined into one table.
5. The daily vehicle-trip table for Home-Based Work, Home-Based Other, Non-Home Based and Through trips is then used to generate the intrazonal trip file and terminal volume file for PC-DTIM.
6. The daily vehicle-trip table is then used to assign trip volumes onto links and when all trips have been processed, adjusts the link travel times based on congestion. In this case assignment is also done separately by trip purpose to generate link volumes by trip purpose and in percent format.
7. Step 6 provides a new loaded network with link volumes in percent format by trip purpose which is then used to generate the link file containing the link data and volumes for PC-DTIM.

FINDINGS AND DISCUSSION

A. Travel Demand:

The three TOD scenarios have the lowest VMT and vehicle hours travelled (VHT). LRT plus all-day road pricing (30 cents/vehicle-mile) has the lowest vehicle hours of delay (VHD). The two LRT with pricing alternatives have low VMT and vehicle hours.

Peak-period road pricing reduced transit travel by pushing many auto drivers into HOVs. Flat pricing (30 cents) did not do this, in general. Interestingly, however, LRT+30 cents produced higher transit ridership than TOD+30 cents. It appears that the surface street congestion caused by the higher densities in the TODs made drive-to-transit fall off somewhat

more than walk-to-transit. But the fact that both types of transit trips fell indicates that because the TODs are near to freeways it became easier to travel by auto in the TOD scenarios, even with all-day pricing, because of the time savings due to the clustering near to the freeways.

The LRT scenario has a lower VMT than does LRT+Pricing, because pricing reduces peak-period trips and congestion and so auto travel is faster and therefore these trips are longer. This illustrates the fact that some pricing measures will reduce VMT, while others, such as peak period tolls, are likely to reduce congestion and increase VMT. Most agencies think that they can reduce congestion and VMT at the same time. This may be difficult or impossible.

The No-Build scenario has lower VMT than does the HOV scenario, a counterintuitive finding for most agencies. This is because the HOV alternative adds HOV lanes to most of the inner freeways, which takes many cars off of the mixed-flow lanes, thereby reducing congestion for single-occupant autos and increasing speeds and trip lengths and reducing transit ridership.

To account for the slight differences across the alternatives in person-trips, which is due to rounding in the many MINUTP calculation steps, we factored the TOD VMT up to make account for its smaller total person-trips ($\times 1.00404$). The resultant corrected VMT, 47.00, does not change our findings.

We also need to ask if the models used are capable of fully simulating the effects of the TDM policies tested. The effects of fuel taxes and parking charges are fairly well-represented in terms of mode choice. Such increases in cost would also affect auto ownership by households and this behavior is not modeled. Large price increases would also affect trip lengths by shortening them somewhat, but this behavior is also not simulated. These model weaknesses will produce projections that underestimate the reductions in VMT due to fuel and parking pricing. Peak-hour pricing is very imperfectly represented, because the model is a daily travel model with factoring used for peak-hour assignments. In the peak-period pricing scenarios, we charged per-mile tolls for home-based work trips and this moves travelers into HOVs. This probably represents the effects of the tolls fairly well. However, the non-work trip mode shares are factored off the work trip mode shares and so

the model may overrepresent total HOV and transit trips. It is unclear if VMT is overprojected or underprojected when all three pricing policies are simulated together. The flat toll of 30 cents/mile is probably simulated more accurately than the peak tolls. The trip generation and mode choice model steps have no land use variables in them and so land use density and mix affects only trip distribution. Mode choice is affected by the increase in households within short walk access times to rail stations, but not by other land use variables, such as mix. There is no auto ownership step, which would take into account the effects of mixed land uses on reducing auto ownership. The VMT reductions from the land use policies are underprojected by the model.

TABLE 1: SUMMARY OF TRAVEL RESULTS

| SCENARIO | VMT (M) | VHT (K) | VHD (K) | TRANSIT TRIPS | HOVTs (M) |
|-------------|------------|------------|------------|------------------|--------------|
| No Bld | 49.28 | 1198 | 349.9 | 74,910 | 1.33 |
| HOV | 51.09 | 1225 | 320.3 | 117,310 | 1.33 |
| HOV+Pr | 49.56 | 1187 | 289.7 | 86,088 | 1.50 |
| LRT | 48.97 | 1188 | 387.0 | 126,557 | 1.32 |
| LRT+Pr | 49.25 | 1178 | 273.5 | 92,287 | 1.50 |
| LRT+30¢ | 48.14 | 1152 | 249.3 | 243,949 | 1.39 |
| TOD | 46.81 | 1136 | 334.0 | 151,149 | 1.32 |
| TOD+Pr | 45.66 | 1106 | 301.1 | 104,107 | 1.49 |
| TOD+30¢ | 45.83 | 1112 | 306.7 | 162,629 | 1.34 |
| <hr/> | | | | | |
| Ranges | | | | | |
| from No Bld | 7.0% | 7.2% | 21.8% | 117.1% | 12.8% |

Comparison with Previous Travel Demand Studies:

Our results are broadly compatible with those of the studies reviewed above. Our LRT+Pricing and LRT+30 cents scenarios reduced VMT, compared to the HOV scenario, but less than did similar packages of policies evaluated in the Bay Area and in Southern California (4-6% versus about 10%). Reasons may include: we modeled a \$2/gal. fuel tax as only \$0.60, to account for the low long-run elasticity of demand for miles travelled (-0.3); our region has poor transit service compared to the Bay Area and parts of Southern California; our freeways are uncongested compared to the other two areas; and our model is daily with factoring for the peak hour, rather than separately calibrated for peak and non-peak traffic, as is the case in the other two regions.

Our land use policies had an effect roughly similar to those reviewed above. We projected very optimistic levels of density and mix in our TODs, levels that would not easily be achieved. The Portland, Oregon, study showed a 14% reduction in VMT for the region. Their employee parking pricing was \$3, about the same as ours, but it only applied to work trips and it only applied in the western sector. Transit was free to all work destinations in the western area, however. Given that no auto travel or fuel pricing measures were simulated and the policies were only applied in a large portion of the region, the Portland VMT reductions are larger than ours. This is probably because their models are more sensitive to congestion, land use changes, and pricing.

B. Emissions Results:

Emissions are largely a result of trips, especially those with cold starts (which are a fixed percentage of all trips in this modeling), and of VMT, especially VMT under 15 mph and over 50 mph. We ran the summer inventory emissions, which are higher than the winter inventory for all pollutants except CO. The scenarios with low emissions are those with low VMT, low total vehicle hours, and low vehicle hours of delay (Table 2).

The lowest energy (fuel) use is for the three land use (TOD) scenarios, with LRT next best. The two LRT with pricing scenarios have higher fuel consumption than do other scenarios even though they have lower VMT and VHT and lower lane-miles of congestion. We cannot explain this and so cannot defend these projections. All model calculations cannot be reported with these official state models.

Evaporative emissions are unchanged across the alternatives and so we will not discuss them. CO, the winter hotspot pollutant, cannot be reliably evaluated on a regional basis, since the violations occur typically locally at large intersections and parking areas and sometimes in urban street canyons. TOG and NOX, the ozone precursors, are somewhat correlated in this analysis, because they both rise for very low and for high vehicle speeds. TOG, however, is much more of a problem at very low speeds (under 15 mph) and NOX rises more rapidly at high speeds (above 50 mph), which accounts for some of the differences in the rankings. CO also rises sharply at very low speeds. TOG and NOX also have different emission rates for cold and hot starts.

The TOD alternatives have the lowest emissions of TOG and NOX (and CO). The No Build scenario has the highest TOG and CO, but HOV has the highest NOX. Of the two policies actually officially considered in the region, LRT is superior to HOV for all pollutants, especially for NOX. Apparently, the new HOV lanes permit travel at high speeds and this increases NOX, compared to not adding freeway lanes in the LRT scenario. The TOD scenario without pricing is almost as good as with pricing, and certainly easier to implement. Likewise, LRT without pricing is almost as good as with pricing, and easier politically.

We consider the emissions projections to be very approximate, however,

TABLE 2: EMISSIONS AND FUEL USE

| SCENARIO | TOG | CO | NOX | FUEL |
|----------|-------|--------|-------|------|
| No Bld | 19.53 | 306.35 | 45.72 | 2.25 |
| HOV | 18.73 | 305.17 | 48.19 | 2.26 |
| HOV+Pr | 18.63 | 302.83 | 47.67 | 2.24 |
| LRT | 17.54 | 280.65 | 42.79 | 2.01 |
| LRT+Pr | 17.37 | 274.96 | 41.79 | 2.30 |
| LRT+30¢ | 17.32 | 273.52 | 41.53 | 2.30 |
| TOD | 17.31 | 276.73 | 41.67 | 1.95 |
| TOD+Pr | 17.26 | 275.17 | 41.60 | 1.95 |
| TOD+30¢ | 17.22 | 274.37 | 41.44 | 1.94 |

due to the rather inaccurate speeds output by the travel demand models, which are not calibrated on average link speeds or on average facility speeds. This is a problem common to most travel models in the past. However, studies such as this performed in other regions may result in significant differences in emissions rankings. The new California emissions

models (with EMFAC7F emission factors), linked to travel demand models that produce better speed projections than in the past, will result in more reliable rankings.

CONCLUSIONS

In this research, we reviewed the literature on land use policies and on auto pricing, in order to identify promising policies to test in the Sacramento region. We tested the specific policy sets with a four-step travel demand model and fed this travel data into the California emissions models.

Our results show that it is difficult to reduce both congestion and emissions. The scenarios with the lowest VHD (LRT+Pricing, LRT+30 cents) did not have the lowest VMT and emissions. This presents a problem to transportation agencies, most of which are attempting to reduce congestion and meet air quality standards, often by building new HOV lanes on freeways.

Building new HOV lanes in this region appears to be worse than No Build on VMT and NOX. It is better on TOG and about the same on CO and energy. NOX reductions must be shown in ozone nonattainment regions, compared to the No Build case, however. Building new HOV lanes does not seem like a wise policy, especially since it competes with LRT for funding. Take-a-lane HOV with pricing, studied by us in another project, has lower VMT but higher emissions and should be studied further. There are many successful take-a-lane HOV projects in the U.S. LRT is substantially better than HOV on travel reduction, all emissions, and fuel use. It is probably a safe policy and the TOD policy improves it.

The TOD scenarios generally are the lowest in VMT, emissions, and energy use. Lower densities and different mixes of employment and housing need to be investigated. Also, better access to rail stations for drive-to-transit travelers needs to be provided with extra road lanes in the peak direction (pull the parking) or circulator shuttlebuses need to be simulated, to overcome the local congestion in the TOD zones.

We found that peak-period road pricing plus fuel and parking pricing increased VMT, compared to LRT alone, because it increased auto 2+ use enough to speed up travel and draw a lot of people off of transit. Peak-period pricing should be studied more carefully. It reduces emissions slightly when used with LRT or with TODs, but it decreases transit trips

when used with LRT, compared to LRT alone. Peak-period pricing reduces congestion enough to attract auto travellers back onto the road. Other policies, or better-designed land use and pricing policies may work better. Perhaps pricing should be phased in, to keep road congestion at needed levels.

The clearest conclusion, however, is that models such as the ones used here are incapable of providing projections in which one can be confident that differences of a few percent are meaningful. Even though the results seem reasonable, if treated as sensitivity tests, policy makers interested in absolute levels of pollutant emissions, or even in relative rankings across hotly debated alternatives, can not feel comfortable with models that omit several classes of behavior entirely. Unfortunately, many agencies have models with similar weaknesses.

The accurate evaluation of new freeway capacity versus TDM options is particularly important for this region for three reasons: 1. a system of new HOV lanes is an adopted policy, 2. this region has the highest percentage of VOC (TOG) from mobile sources of any region in the U.S., and 3. the region is under a court order from a lawsuit under the federal clean air act, which requires it to do better planning and analysis. The regional agency has recently developed a much better set of travel models, for these reasons.

We will replicate these tests with the new regional model set in 1994. That set will include a new auto ownership model, walk and bike modes, separate peak and offpeak models, peak spreading, better link capacity data and post-model checks to improve speed projections, logit models for all trip purposes, intersection delays, and composite (multiple-mode) impedences. Work trip distribution will be in a logit formulation, as a joint mode-destination choice model. Assigned speeds will be fed back to nonwork trip distribution. Accessibility variables are included in the logit auto ownership step. Land use variables are included in auto ownership and in mode choice, making the models more sensitive to land use policies. All models have been estimated on a 1990 household travel survey. In addition, the agency will implement a land allocation model (DRAM/EMPAL). Also, we will use the new California EMFAC7F emission factors, which have higher emission rates for very low and for high speeds. The addition of standing evaporative losses to TOG will show the importance of reducing vehicle ownership.

NOTES:

1. Robert A. Johnston is a Professor of Environmental Studies at the University of California, Davis, CA and a Researcher at the Institute of Transportation Studies there. His other research areas include legal methods of regional and statewide habitat protection, impact assessment policy, and land use plan implementation.
2. Raju Ceerla is Associate Transportation Planner at the Association of Monterey Bay Area Governments. He was a Research Associate at the University of California at Davis.

REFERENCES

ABAG, 1990. "Increasing Transit Ridership and the Efficiency of Land Use While Maximizing Economic Potential." Working Paper 90-2. Association of Bay Area Governments, Oakland, CA, October.

Aschauer, 1990.

Bae, C. "Air Quality and Travel Behavior, Untying the Knot." Journal of the American Planning Association, Vol. 59, No. 1, Winter 1993, pp. 65-75.

Bay Area Air Quality Management District. 1991. "Bay Area '91 Clean Air Plan, Volume 1," San Francisco, CA, October.

California Air Resources Board, 1993. "The Linkage Between Land Use, Transportation, and Air Quality," Office of Air Quality and Transportation Planning, Sacramento, CA, March.

California ARB, 1991. "Methodology to Calculate Emission Factors For On-Road Motor Vehicles," California Air Resource Board, July, Sacramento.

California ARB, 1992. "Supplement to Methodology to Calculate Emission Factors For On-Road Motor Vehicles, July 1991," California Air Resource Board, June.

California Energy Commission, 1993. "Background Information for the Transportation Cost Workshop." Energy Technology Development Division, Technology Evaluation Office, April 8.

Caltrans, 1993. "User's Guide To The PC Version of The Direct Travel Impact Model", Release 93.1, Feb. 1993, Sacramento, CA.

Cambridge Systematics, Inc., 1992. "The LUTRAQ Alternative: Analysis of Alternatives, An Interim Report." Boston, MA, October.

Cameron, Michael, 1991. "Transportation Efficiency: Tackling Southern California's Air Pollution and Congestion." Environmental Defense Fund, Los Angeles, March.

Colman, Steven B., et al., 1991. "Back to the Future: Trip Generation Characteristics of Transit Oriented Developments." Paper for AWMA meetings?

COMSIS Corporation, 1991. "MINUTP Technical User Manual," Jan.

Cope, David R., Hills, Peter, and James, Peter, 1984. Energy Policy and Land-Use Planning. Pergamon Press, New York.

Decorla-Souza, Patrick and Kane, Anthony, 1992. "Peak Period Tolls: Precepts and Prospects," Transportation Research Record 19:4, pp. 293-311.

Downs, Anthony, 1992. Stuck in Traffic : Coping with Peak-Hour Congestion. The Brookings Institution (Washington D.C.).

Giuliano, Genevieve, 1992. "Is Jobs Housing Balance a Transportation Issue?" University of

California Transportation Center, University of California, Berkeley., Reprint no. 133.

Harvey, Greig and Deakin, Elizabeth, 1990. "Mobility and Emissions in the San Francisco Bay Area: Draft Working Paper." Prepared for the Metropolitan Transportation Commission. Oakland, CA. April.

Hau, Timothy D., 1987. "Using a Hicksian Approach to Cost-Benefit Analysis in Discrete Choice: An Empirical Analysis of a Transportation Corridor Simulation Model," Transportation Research: B, Vol. 21B, No. 5, pp. 339-357.

Hau, Timothy D., 1992. "Congestion Charging Mechanisms for Roads: An Evaluation of Current Practice." WPS 1071, The World Bank, Washington, D.C., December.

Jones, Peter, 1992. "A Review of Available Evidence on Public Reactions for Road Pricing." London Transport Unit, Dept. of Transport, (2 Mansham St., London SW1P 3EB)

Keyes, Dale L., 1976. "Energy and Land Use: An Instrument of US Conservation Policy?" Energy Policy, Vol. 4, No. 3, September, pp. 225-236.

Keyes, Dale E., 1982. "Energy for Travel: The Influence of Urban Development Patterns," Transportation Research: A, Vol. 16A, No. 1, pp. 65-70.

Lee, Douglass B., 1992. "A Market-Oriented Transportation and Land Use System: How Different Would It Be?" Paper for the conference on Privatization and Deregulation in Passenger Transportation, Tampere, Finland, June, 1991. U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA.

May, A.D. 1992. "Road Pricing: An International Perspective," Transportation, Vol. 19, pp. 313-333.

MTC, 1990b. "Final Report: 2005 HOV Program Prioritization, Deliverable #8." Prepared

for the Metropolitan Transportation Commission by Cambridge Systematics, Inc. August 22.

MTC, 1990c. "Travel Forecasting Results: Land Use Alternative with Transit Capacity Alternative Networks. Technical Note #6." Memo from Chuck Purvis to file. Metropolitan Transportation Commission, Oakland, CA. December 28.

Mogridge, Martin J. H., 1986. "Road Pricing: The Right Solution for the Right Problem?" Transportation Research: A, Vol. 20A, No. 2, pp. 157-167.

Morrison, Steven A., 1986. "A Survey of Road Pricing." Transportation Research: A, Vol. 20A, No. 2, pp. 87-97.

Newman, Peter W. G. and Kenworthy, Jeffrey R., 1989. Cities and Automobile Dependence: A Sourcebook. Gower Technical, Brookfield, MA.

Nowland, David M. and Stewart, Greg, 1991. "Downtown Population Growth and Commuting Trips," Journal of the American Planning Association, Vol. 57, No. 2, (Spring), pp. 1-11.

Parsons Brinckerhoff Quade & Douglas, Inc., 1990. "Sacramento Systems Planning Study, Task 4.3/4.5 Travel Model Development, Draft," Sacramento, Sept.

Replogle, Michael, 1990. "Computer Transportation Models for Land Use Regulation and Master Planning in Montgomery County, Maryland." Transportation Research Record, 1262, pp. 91-100.

Ruiter, Earl R. and Dial, Robert B., 1979. "Equilibrium Modelling." In Hensher and Stopher, 1979, pp. 207-215.

SANDAG, 1991. "The Relationship between Jobs/Housing Balance and Travel Patterns in the San Diego Region." San Diego Association of Governments, San Diego, July.

Congress, Washington, D.C., April.

Wachs, Martin, 1989. "Thought Piece on the Jobs/Housing Balance," paper for the City of Los Angeles Workshop on Jobs Housing Balance, Los Angeles, October.

Walsh, Michael P., 1991. "Transportation Activity Trends and Their Implications for Global Warming: The US in an International Context." Paper for the Transportation Research Board conference on Transportation and Global Climate Change: Long-Run Options, Asilomar, CA, August.

Watterson, W. Timothy, 1991. "Linked Simulation of Land Use and Transportation Systems: Developments and Experience in the Puget Sound Region." Paper for the Conference on Transportation and Global Climate Change: Long-Run Options, Transportation Research Board, Asilomar, CA, August.

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

Willson, Richard W. and Shoup, Donald C., 1990. "Employer-Paid Parking: The Problem and Proposed Solutions." Paper for the Association for Commuter Transportation conference, Seattle, WA. December.

SCAG, 1988a. "Transportation, Land Use, and Energy Conservation Measures," Draft part of Air Quality Plan, Southern California Association of Governments, Los Angeles, May.

SCAG, 1988b. "Draft Regional Mobility Plan: Technical Appendices." Southern California Association of Governments, Los Angeles, October.

Schipper, Lee and Meyers, Stephen, 1991. "Energy Use and Human Activity: Global Developments and Prospects." Paper presented at the Transportation Research Board conference on Transportation and Global Warming: Long-Range Options, Asilomar, CA, August.

Sewell, W.R. Derrick and Foster, Harold D. 1980. "Analysis of the United States Experience in Modifying Land Use to Conserve Energy," Working Paper No. 2, Lands Directorate, Environment Canada.

Shoup, Donald C., 1992. "Will Cashing Out Parking Subsidies Change Urban Form?", Paper for UCLA Extension Course on Travel Pricing. Graduate School of Architecture and Urban Planning.

Small, Kenneth A., Winston, Clifford., Evans, Carol A., 1989. "Road Work : A New Highway Pricing and Investment Policy." The Brookings Institution (Washington D.C.).

Small, Kenneth A., 1983. "The Incidence of Congestion Tolls on Urban Highways." Journal of Urban Economics, Vol. 13 (January), pp. 90-111.

Small, Kenneth A., 1992. "Using the Revenues from Congestion Pricing," Transportation Research: A, Vol. 19A, No. XX, pp. 359-381.

Starkie, David, 1986. "Efficient and Politic Congestion Tolls." Transportation Research: A, Vol. 20A, No. 2, pp. 169-173.

U.S. Office of Technology Assessment, 1988. "Urban Ozone and the Clean Air Act," U.S.