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REGIONAL SIMULATIONS OF HIGHWAY AND TRANSIT ITS: TRAVEL, EMISSIONS, AND ECONOMIC WELFARE EFFECTS

Robert A. Johnston and Caroline J. Rodier
Division of Environmental Studies
University of California
Davis, CA 95616
Phone: 916 582-0700
Fax: 916 582-0707
rajohnston@ucdavis.edu

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Robert A. Johnston is a Professor and Caroline J. Rodier
is a Research Associate in the Division of Environmental Studies
and in the Institute of Transportation Studies at the University of California, Davis.

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Abstract:

Various problems in the regional modeling of ITS are discussed. We then review previous research on the effects of ITS highway and transit technologies on travel and emissions and critique these studies. Then, we outline our past research methods and findings and describe the weaknesses of these studies. This review is followed by descriptions of two recent projects, one simulating automated freeways and one simulating advanced transit technologies. These two types of technologies pose substantial and different sets of problems for modelers. We describe the economic welfare model we adapted and applied in these projects. We conclude with an outline of our current modeling improvements and how these relate to the other advancements being made in related modeling areas.

Introduction:

Our research differs considerably in its focus from most ITS work. While considerable funding has been directed at the development and testing of technologies, we assume that the technologies work and ask whether ITS is worthwhile.

For several years, we have performed systems-level evaluations of advanced technology roadway and transit systems. The early papers were conceptual and broad, while the more recent work has focused on emissions and economic welfare. These recent projects have used the Sacramento, California region as our test area, because the travel models for this region are relatively sophisticated. Our most recent methodological contributions include the implementation of a traveler welfare model, linked to the travel models and the initial application of a land use/transportation model.

First, we will identify the methodological issues in performing regional evaluations of ITS. Then, we will briefly review our past work and describe the methods used in the most recent studies in some detail and outline the findings. Finally, the integrated urban modeling that we are just beginning will be briefly described. The emphasis throughout will be on methods, with only summaries of our findings given.

A. Problems in Systemwide Modeling of ITS

Ostria and Lawrence [1] reviewed the various forms of ITS and found that some programs, such as enhanced inspection and maintenance, transit scheduling, and vehicle pricing, are likely to reduce emissions, whereas incident management and route guidance may increase NOx, and vehicle control may increase all emissions. This article is conceptual, with reference made only to theory and to general findings from earlier studies. It is, however, a very useful overview of these issues.

The reason that vehicle control (Automated Highway Systems, or AHS) might increase emissions is that speeding up travel with large regional capacity increases can be expected to increase tripmaking and trip lengths, single-occupant auto mode share, auto ownership, and suburban growth on the metropolitan edge. The effects of all these changes on emissions is complex, because the lower emissions per vehicle-mile expected in automated platoons is traded off against the higher vehicle miles traveled (VMT). Only state-of-the-practice travel models that have elastic auto ownership, trip generation, trip distribution, and mode choice (these vary as accessibility varies) can be used to evaluate AHS accurately. One then needs to factor emissions per vehicle-mile, based on microsimulation of automated vehicles. As we show below, all of these travel modeling methods are in use and the microsimulation of individual vehicles is just now coming into use.

The economic effects of AHS are also not obvious in advance. We could see net benefits for travelers in regions with severe congestion and suppressed tripmaking. However, in most urban regions, which are only moderately congested and travelers can still move off-peak, we would expect welfare losses to travelers from the added distance traveled and from the additional, low-value trips. We adapted a traveler welfare model to use aggregate zonal data, typical in regional modeling, in order to be able to evaluate these effects. These models have shortcomings, however. The extra travel costs could be offset by gains in utility from better quality housing farther out from the urban center. Only integrated (land use/transport) urban models can represent and measure these changes in locator welfare and no such model with land market bidding represented has ever been used in the U.S., although such models have been applied in many regions in Europe, Asia, and Latin America. At the end of the paper, we describe our initial calibration of such a model on datasets for the Sacramento region.

In a paper showing the need for empirical simulation, Brand [2] proposed to evaluate ITS projects with a mix of economic efficiency criteria and overlapping demand criteria, while noting that these groups of measures overlap. The use of such overlapping criteria confuses evaluations with double-counting and makes the weighting of the categories of measures overly political. A comprehensive economic evaluation should be done, instead, and the effects on other criteria discussed outside the economic evaluation. Brand's method of economic analysis explicitly assumes that capacity increases will not induce additional trips or longer trips, while acknowledging that these assumptions are unrealistic. He then uses these unrealistic--and incorrect--assumptions to demonstrate that capacity increases will produce net benefits. This paper serves to illustrate the dire straits into which agencies and others interested in ITS could find themselves if they do not develop sound evaluation methods based on economic theory.

Over the past several years, our development of increasingly complex models has paralleled the increasing concern over induced travel from capacity additions of any kind. In the U.S., the concerns have centered on the effects of the extra travel on emissions, while in the U.K. the concerns have focused mainly on the economic welfare effects.

A Transportation Research Board committee examined the effects of increased roadway capacity on emissions and found that the weight of the evidence suggested a travel elasticity with respect to travel cost of up to about -0.5, meaning that if we speed up a traveler 100% (reducing time costs by about 50%) he will go about 25% farther [3]. The committee also agreed that capacity increases will increase development of lands at the metropolitan edge, where travel per capita is highest. Overall, though, this advisory body found that the emissions increases would be small and part of a declining emissions burden brought about by cleaner tailpipe technologies. They were examining typical freeway extensions and widenings, however, and not AHS, which can increase capacity much more drastically. In our work, we took care to examine AHS scenarios with different speeds and with all freeway lanes automated and with just one lane automated, in order to evaluate a great range of capacity increments.

Due to concerns over this issue of induced travel, the EPA adopted regulations in 1993 requiring that, in serious, severe, and extreme ozone nonattainment regions, travel models represent induced trip lengthening with feedback from the traffic assignment step to the trip distribution step and encouraged the representation of induced tripmaking with a similarly elastic trip generation step (40 CFR 51.452(b)). Most of the affected regional agencies have added these capabilities to their travel models. The related requirement that, in these regions, the travel models must "utililize...a logical correspondence" between land use patterns and future transportation systems has compelled some of the affected agencies to implement integrated urban models, which is ongoing and largely unsuccessful, due to the difficulty of these U.S. models. We believe that the class of urban models that we are implementing in our research is superior to the model types in use in the U.S. The third type of legal requirement that relates to our research program is the USDOT regulation under ISTEA that metropolitan transportation plans must "consider" the overall economic effects of the plans (23 CFR 450.316). These requirements also apply to Major Investment Studies for projects (23 CFR 450.318). We go through these legal issues to show that, in the case of transportation planning in large metropolitan regions, theoretically accurate modeling of induced travel and of economic welfare happens to be legally required.

The U.K. transportation planning process has long relied on economic evaluations, as have the procedures in most developed and developing nations. Since theoretically sound economic welfare evaluation is new to the U.S. and still not being done by any regional agency that we know of, in spite of the regulatory requirement, we need to examine the experience in the U.K., where the issue of induced travel is also a concern. The report of the U.K. Standing Committee on Trunk Road Assessment [4] is much more detailed in its treatment of the empirical and modeling literature on induced travel and in its examination of the economic effects of induced travel than was the U.S. report. The U.K. SACTRA group concluded that the elasticity of demand with respect to cost can range as high as -1.0 in highly congested urban regions and that urban travel modeling must represent this elastic trip distribution and tripmaking. Furthermore, the report went on to show how drastically induced travel can reduce the net benefits of large projects. In many empirical cases, induced travel made the net benefits to society (including the project capital and O&M costs) go negative. Even induced travel increases of a little as1-3% in vehicle-miles could reduce net benefits by as much as 20-30% ([4], p. 151), due to the slowing down of all traffic. This phenomenon is examined in their report with a review of several sophisticated modeling exercises where elasticities were varied and the finding is robust across a wide range of assumptions ([4], pp. 135-162). So, from the standpoint of regional economic welfare evaluations of AHS, we must get our travel modeling right, if we are to get our economic modeling right.

The U.K. Department of Transport has implemented the SACTRA recommendations in several manuals. Induced travel must be represented whenever networks are close to capacity in the modeling year (year 15), or elasticity for travel with respect to cost is high as in urban regions with high quality transit service, or the project or plan will greatly lower travel costs [5]. Land use changes reliant on the plan or project must also be modeled, at least with different land use location assumptions derived through consultations with local planners. For simple, initial sensitivity tests, elasticities of travel (VMT) with respect to cost are to be used and these range up to -1.0 for year 15 in congested urban regions. The recommended elasticity for tripmaking is -0.1 for year 15. These are all rather high values and show the earnest attempt to represent induced travel in U.K. transport planning.

B. The Overall AHS Research Agenda

In our initial ITS paper, we identified several potential problems for AHS, the extreme case of capacity addition [6]:

1. Capacity. The high costs of the initial stages of AHS deployment will likely not be rewarded with large capacity increases. The intermediate stages, with mixed automated and nonautomated lanes may experience safety problems and will certainly require a dedicated merge lane, to get into the fast platoons in the left lanes. Off-ramps will need to be widened and on-ramps will need to be lengthened, to accomodate the necessary accelerations.
2. Air Quality and Noise. Higher volumes and speeds can be expected to increase emissions and noise. With clean vehicles in the future, the emissions issue may go away.
3. Safety and reliability. The in-vehicle software, out-of-vehicle software, driver, vehicle, and roadway must perform exquisitely in all kinds of weather. The switches to and from automatic control must work under every circumstance. The on-board screen must not take the driver's attention away from the road at critical times. Driver skills could be a problem, in terms of age and literacy. Redundant control systems will be required on the vehicle. A few large accidents could kill the idea, politically.
4. Costs, Benefits, and Equity. AHS may not pay for the traveler. It may not pay for the region or nation, when all external costs are included in a social welfare evaluation. The poor will be disadvantaged by the higher vehicle costs. One can expect greater sprawl and perhaps greater spatial segregation of households by income.
5. Privacy. Central computers will probably be required, to some extent, to manage the system. Even with encryption of vehicle identifiers and the regular purging of computer memories, some

people will be anxious about their being tracked. In the past, public and private organizations have lied about data storage and its use and so the public can justifiably be skeptical.

6. Public-Private and Local-State Cooperation. There will be monumental political issues, concerning the state or regional control of local facilities, to coordinate traffic. The liability issues are also thorny. Who is at fault when there is an accident, the vehicle manufacturer, the vehicle maintenance firm, the roadway operator, the roadway owner, the roadway builder, the roadway designer, the driver, the other driver, the software designer, the software operator, or...?

This list is not intended to discourage ITS technologists or theorists, but to get them to see the many issues that need to be addressed in order to get continuing support for ITS from Congress and the states. In our subsequent papers, reviewed below, we focused in on the effects of AHS and transit technologies on travel, emissions, and traveler economic welfare.

C. Modeling Automated Highway Systems (AHS)

We will review the literature on systems modeling of AHS and then discuss our methods and findings from a recent modeling exercise, using a state-of-the-practice travel model.

1. Review of Relevant AHS Systems Studies

We identified the demand-inducing aspects of automation as a possible problem in an early overview of the policy issues involved with the automation of urban freeways [6]. In our first regional modeling research, we ran a traditional travel demand model for daily travel and equilibrated the assignment, trip distribution, and mode choice steps on assigned impedances and found that freeway automation increased travel, when compared to the no-build case and to the preferred Sacramento region policies for expanding light rail transit (LRT) and building new freeway high occupancy vehicle (HOV) lanes. More interestingly, some freeway automation scenarios reduced delay considerably while some did not, compared to the conventional alternatives. Generally, emissions were increased in the automation scenarios. We made crude projections of traveler costs, including external costs and government subsidies and found that the various automation scenarios were more costly than the LRT, HOV, and No Build ones [7].

In past research, we also performed a break-even evaluation of the time savings necessary to recoup the costs of automating various types of vehicles [8]. Using high and low values for capital and operating costs, we found that automation clearly was financially worthwhile for the owners of heavy-duty vehicles but would likely not pay for light-duty vehicles. This presents a problem, since the Caltrans (California DOT) program until recently was oriented toward light-duty vehicles. Underwood [9] found that cost to the consumer was the first-ranked issue for a panel of experts. As a result of our paper and Underwood's findings, we identified automated HOV lanes as one possible system that could be cost-effective for light-duty vehicle owners (assuming sharing of costs among all occupants). Neither these cost findings nor those in our first modeling paper (discussed just above), however, mean that AHS is not worthwhile to the traveler. Their benefits could increase more than their costs. Our recent research reviewed below addresses this issue by using utility-based models that measure net benefits to the traveler.

Only one other regional network-based evaluation of AHS has been done. SCAG [10], in cooperation with Caltrans, performed a study of automated freeways in Southern California for the year 2015. The identification of market penetration scenarios was useful; however, the travel models were run on one set of trip tables in order to save money (the SCAG Urban Transportation Planning (UTP) models cost about $10,000 for one run, and full iteration takes several runs). The automation scenarios were at 55 mph (the models capped speeds at 55 mph, and so higher speeds could not be simulated). Capacity was set at 6,000 vehicles per hour per lane. Congestion was projected to decrease on freeways and arterials and increase on ramps. There was a 6% reduction in emissions, due to less VMT at low speeds. The modeling, however, did not account for the effects of increased speeds on tripmaking or trip lengths, which would go up nearly proportionately in this very congested region. Also, the model was run for the

A.M. peak only, so the effects of automation on off-peak travel were not projected. Considerable increases in VMT at high speeds could be expected during off-peak periods. This study shows the need for improved modeling and for affordable software (running on PCs).

Hansen et al. [11] performed a comprehensive empirical study of the effects of generally increasing highway capacity on travel using longitudinal panel datasets of metropolitan roadway lane-miles and VMT in California. They found that the medium-term (arc) elasticities (_ VMT/ _ lane-miles) averaged about 0.5 to 0.6, for periods of 6 to 9 years after the capacity expansions. The literature was in fairly consistent agreement with their own data. The authors note that these elasticities would be higher now, because congestion levels are worse. This report agrees broadly with the SACTRA findings in the U.K., discussed above. Although the Hansen study did not analyze AHS directly, it shows the need to represent induced travel in modeling.

2. Methods

Travel Demand Modeling

In our most recent AHS study, we used the Sacramento Regional Travel Demand Model (SACMET 94), a state-of the-practice regional travel model that incorporates most of the recommendations made in the National Association of Regional Councils' "A Manual of Regional Transportation Modeling Practice for Air Quality" [12]. Some of the key features of this model include full iteration of model steps on travel costs (so trip distribution is elastic), an auto ownership and trip generation step with accessibility variables (so tripmaking is somewhat elastic), a joint destination and mode choice model, a mode choice model with separate walk and bike modes and land use variables, a trip assignment step that assigns for separate A.M. peak, P.M. peak, and off-peak periods, and an HOV lane use model [13,14]. With this improved model, we could examine the travel and emissions effects of AHS more accurately than in our past work. In addition, the mode choice models in the SACMET 94 model all have a logit specification. This allowed for the development of a consumer (traveler) welfare model. Thus, we examine the consumer welfare effects of automated highway systems (AHS) with the theoretically correct modeling procedure of full model feedback on travel time.

The model system is iterated on level of service variables by mode until the criterion for convergence is met (i.e., A.M. peak trip assignment impedance is within 3% of those in the last iteration). This usually required five iterations of the model for the year 2015. All submodels have been calibrated to regional survey data and traffic count data. SACMET 94 meets the EPA's modeling requirements. We used simple (direct) iteration, but there are other model equilibration methods that can be used if the direct iteration method does not lead to convergence [15].

Emissions Model

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) [16] and the California Air Resources Board's model EMFAC7F were used in the emissions analysis. The outputs from the travel demand model used in the emissions analysis included the results of assignment for each trip purpose by each time period (A.M. peak, P.M. peak, and off-peak). The Sacramento Area Council of Governments provided regional coldstart and hotstart factors for each hour in a twenty-four hour summer period.

Consumer Welfare Model

Kenneth Small and Harvey Rosen [17] illustrate how a consumer welfare measure known as compensating variation can be obtained from discrete choice models:

$$CV_i = -(1/\lambda\iota)\{ [\ln \Sigma_i \exp V_i(p^f)] - [\ln \Sigma_i \exp V_i(p^0)] \}$$

where $\lambda\iota$ is the individual's coefficient of travel cost divided by income, V_i is an individual's utility, p^0 indicates the initial point (i.e., before the policy change), and p_f indicates the final point (i.e., after the policy change). Small and Rosen show that the marginal utility of income is provided by the negative of the coefficient of the variable cost divided by income in the logit equation. Thus, compensating variation is the difference between the natural log of the sum (logsum) of the individual's utility at the initial and final points divided by the individual's marginal utility of income.

A method of application is developed for the mode choice models in the Sacramento Regional Travel Demand Model. The SACMET 94 mode choice models use a logit specification. However, person trips, rather than individuals, are the unit of analysis in these models. Person trips are generated for a number of household groups. Thus, the expression for compensating variation in the context of the SACMET 94 mode choice models for household groups (h) within each income class (i) is

$$CV_h = -(1/\lambda_i)\{[\ln \Sigma_j \exp V_j (p^f) \times trips_{ij}] - [\ln \Sigma_j \exp V_j (p^0) \times trips_{ij}]\}$$

where λ_i is the coefficient of the cost divided by income variable for an income class, V_j is the household's utility across modal alternatives for a zone pair, and $trips_{ij}$ is equal to the number of person trips made by a household class for a zone pair. CV_h can then be summed to obtain consumer welfare by income class or total consumer welfare.

Measures of compensating variation could not be obtained for the non-home-based and the home-based school mode choice models because they lack cost and income variables, the absence of which makes it difficult to obtain the marginal utility of income for these trip types. Thus, 63% of the region's total trips are included in the analysis of compensating variation. However, approximately 80% of trip utility is included in the analysis because work trips are valued more highly than nonwork trips.

Since the mode choice models include perceived operating costs (5 cents per mile), rather than actual operating costs, total VMT is obtained from the model and then multiplied by 35 cents. Based on a review of the literature, we assume total operating costs are 40 cents [18].

The change in total operating costs per mile from the base case and the alternative modeled is then added to the compensating variation figure.

The SACMET 94 regional travel demand model is run in the theoretically correct manner with full model iteration, and thus expanded roadway capacity will induce more and longer trips. This has two effects on projections of consumer welfare. The value of new induced trips will provide less benefit than existing travel because the former are trips that are foregone in the presence of congestion and, thus, have less value. In addition, new trips and increased trip lengths due to increased roadway capacity will counteract much of the travel time savings benefits of roadway expansion projects.

Truck freight trips are not included in the analysis of consumer welfare. Such trips generally have a high value. As a result, the welfare gains from scenarios that significantly decrease roadway congestion may be underestimated in this study.

3. Uncertainty in the Methods of Travel Demand Analysis

The SACMET 94 travel demand model is not integrated with a land use model. As a result of using fixed land use inputs, the model underprojects induced auto travel due to major roadway capacity expansions and reduced auto travel due to transit investments and pricing policies.

System equilibrium is assumed in model operation with full feedback from trip assignment to earlier steps until convergence. This implies an elasticity of demand with respect to cost of about -1.0. If the actual transportation system does not attain complete equilibrium (as some research suggests), our running of the model would exaggerate the trip length in scenarios with expanded roadway capacity. However, this exaggeration is likely to be at least offset by the failure to represent land use changes resulting from transportation policies.

The propensity for auto drivers to switch to transit and/or HOV modes in the presence of higher auto travel time and cost is likely underrepresented in the SACMET 94 model. This is an artifact of the cross-sectional data used to estimate the model. Sacramento currently has minimal transit service, one relatively short HOV facility, and comparatively low land use densities (compared to urban areas with high transit use), and thus cross-sectional data on travel behavior collected in this area would contain little variation in transit and HOV mode choice. In addition, if land use densities increased, transit and HOV use would likely be underprojected.

Attributes of modes such as comfort and convenience are generally included as mode specific constants, rather than separate variables, in the mode choice models of most regional travel demand models. This is because such variables are very difficult to forecast into the future. Since automated freeways and highways have not yet been implemented in the U.S. (much less Sacramento), potential beneficial attributes of automated vehicles, over and above those of the drive alone mode, are not represented in the underlying data used to estimate the SACMET 94 mode choice models. As a result, our analysis may underestimate travel and consumer welfare benefits, if such technologies reduced the value of time for travelers.

In addition, the trip assignment step of SACMET 94 lacks the representation of peak spreading or time-of-day choice. Thus, the volume of travel during peak hours may be overestimated for very congested scenarios because the propensity of travelers to move off of the peak is not represented.

The magnitude of each of the foregoing limitations of the travel modeling cannot be identified; however, it appears that many of these limitations may offset one another.

Any limitation in the travel modeling, as described above, that affects the accuracy in estimates of transportation level of service will likewise affect the accuracy of the estimates of emissions and consumer welfare.

Finally, it is widely known that emissions are underprojected by the models used in the analysis in this report. However, this should not affect the rank ordering of the scenarios.

4. AHS Alternatives Modeled

Eight alternatives for the year 2015 were examined in our study. SACOG provided the demographic projections and networks for the 2015 scenarios. The networks include transportation projects listed in SACOG's 1993 Metropolitan Transportation Plan (MTP) [19]. All changes to the input data and model codes are described for each alternative below.

(1) No-Build. In this alternative, all new freeways, expressways, HOV lanes, and transit projects listed in the 1993 MTP and included in SACOG's 2015 network files were removed. New arterials, collectors, and ramps were not excluded from the network files.

(2) Light Rail Transit. New light rail transit projects listed in the 1993 MTP (approximately 61.5 track miles) were included in this alternative; however, new freeways, expressways, and HOV lanes were excluded.

(3) HOV Lanes. This alternatives includes all new HOV lanes, freeways, and expressways described in the 1993 MTP (approximately 184.5 lane miles) but excludes all new light rail projects.

(4) Automated HOV (60 mph). In this alternative, the HOV lanes were automated and set to 60 mph with a 1 second headway. The capacity of the HOV lane was set at 3600 vehicles/hour/lane to reflect the 1 second headway on the links. To the HOV lane network described in (3), one lane was added to all ramps and to both sides of arterial or collector links connecting to automated lanes. In addition, HOV lanes were added to SR 50 where a gap exists in the continuity of SACOG's planned HOV lane network. The new HOV lanes start where I-80 meets SR 50 near the Port of Sacramento and end near the intersection of Freeport Boulevard and SR 50.

(5) Automated HOV (80 mph). In this alternative, HOV lanes were automated and set to 80 mph with a 0.5 second headway. The capacity of the HOV lanes was set at 7200 vehicles/hour/lane to reflect the 0.5 second headway on the links. The HOV lane network described in (4) was

used.

(6) Full Automation (60 mph). In this alternative, all freeways lanes were automated and set to 60 mph with a 1 second headway (as in alternative 4). To the no-build network described in (1), one lane was added to all ramps and to both sides of arterials or collector links connecting to automated freeway lanes.

(7) Full Automation (80 mph). In this alternative, all freeway lanes were automated and set to 80 mph with a 0.5 second headway (as in alternative 5) on the full automation network described in (6).

(8) Partial Automation (60 mph). The network is the same as (7) except that, in this alternative, only one freeway lane, rather than all freeway lanes, is automated. Speeds on this lane are set to 60 mph and 1 second headways are assumed.

5. AHS Findings and Discussion

Travel Results

Since this is primarily a methods review paper, we will only outline our results. Daily trips varied from the future No Build case in expected ways, that is with capacity. The differences in trips ranged from Full Auto 80 (about 2%), then Auto HOV 80, Full Auto 60, Partial Auto, Auto HOV 60, LRT, and HOV (0.28%). VMT varied similarly, but ranging much more widely from 23% (Full Auto 80) to HOV (3%) and LRT (0.06%).

Hours of delay varied inversely with VMT, resulting in differences ranging from -47% (Full Auto 80) to LRT (-2%). Delay varies much more than VMT, due to the nonlinear relationship between volume and speed.

Mode shares were quite invariant, with transit, walk, and bike together not changing more than 1 percentage point from the No Build case (7%). The transit service in this region is poor, even in the future LRT scenario, and so there is not much competition among modes for most zone pairs. As sensitivity tests, we examined a massive investment in LRT, accompanied by strong land use intensification near the rail stations, and got almost 10% transit/walk/bike. We also added parking pricing, peak-period freeway tolls, and a fuel tax to the conventional LRT scenario reported here and got an 11% transit/walk/bike share. These results are broadly compatible with other studies of pricing, rail expansion, and land use intensification near rail stations, so we conclude that the SACMET 94 mode choice models are reasonable.

Emissions

Emissions of TOG, CO, NOX, and PM10 varied in the same order across the scenarios, with few exceptions, so we will look only at TOG. Full Auto 80 was highest (28% above No Build), Auto HOV 80, Full Auto 60, Auto HOV 60 (1%), Partial Auto 60, HOV (1%), and LRT (-0.19%).

In summary, more capacity leads to more emissions, not correcting for smoother flows from automation. We now examine whether such a correction is warranted by available research.

Effects of the Automation of Freeway Lanes on Emissions per Vehicle Mile:

Work with an instrumented vehicle by UC Riverside researchers showed that platooned vehicles reduce emissions per vehicle-mile by about 50%. However, the accelerations and decelerations into and out of the automated lane(s) and even the platoon splitting and merging maneuvers can negate these line-haul benefits if the vehicle enters into a power enrichment state. A constant-acceleration mode cannot be used, because the vehicle enters enrichment at high speeds, and so a constant-power state must be maintained.

This same research group also looked at ramp metering, to evaluate the emissions effects, since AHS will require ramp metering for diagnostic checks of on-board equipment. Results varied greatly because of local ramp geometry (slope, ramp length, etc.), the cycle length of the ramp signals, vehicle mix, and mainline freeway volumes. Even using constant power, vehicles can enter enrichment if ramps are short or steep. Another problem is that when the mainline speeds are high, which is the purpose of ramp metering and of AHS, the required accelerations can take the vehicle into enrichment and offset the emission reductions from smoother flows on the mainline [20].

In our earlier work, we found that AHS, whether partial (some freeway lanes) or full (all lanes), would require a merge lane for speed changes from the nonautomated lanes or from ramps, on congested facilities. Using one lane for merging will reduce roadway capacity substantially, especially on three- or four-lane (directional) freeway segments.

From reviewing this emissions research, it seems that many on-ramps in built-up urban areas will not be useable for AHS, because they are too short or curved or up-sloping. In less-densely developed areas, some ramps can be re-built at high cost. We will still have the problem of stacking vehicles trying to get on the metered ramp, which is a problem even now with metered ramps. Also, with the high volumes in AHS we will have off-ramp queueing problems in the outside lane for several hundred meters or more upstream on the freeway, for some ramps.

Considering all of these factors, it seems that we may or may not be able to reduce emissions per vehicle-mile. It seems that AHS will only produce emissions benefits if vehicles can be designed with closed-loop (on-cycle) emissions controls at higher acceleration rates than present technology allows. These vehicles, however, will be cleaner in non-AHS operation and so the relative changes in emissions from automation may not change.

From this review of modal emissions issues, we conclude that AHS may or may not result in emission reductions per vehicle-mile. A good case cannot be made either way. As a result of this analysis, we did not factor emissions down in our automation scenarios. Clean-fuel vehicles in 10 to 20 years will also not change the relative effects of AHS, but could make the whole pollution issue moot.

Consumer Welfare

We now outline our findings regarding traveler (consumer) welfare, in the aggregate and by income class.

Full Auto 80 caused losses per trip of $0.68, due to additional travel, the added full private costs of which exceeded the time savings of the faster travel. The other automation scenarios also caused losses (of about $0.20 per trip), with one exception. The Full Auto 60 scenario resulted in a gain of $0.23 per trip. HOV resulted in a small loss ($0.04 per trip), again due to the large extra capacity and added VMT, and LRT caused a small gain ($0.02), mainly due to offering a new mode to some travelers. These results correspond to economic theory, which indicates that small capacity additions will increase user welfare in mildly congested networks (such as Sacramento) and new modes will always increase user welfare, at least by a small amount.

Our equity analysis by income class showed that all the automation scenarios resulted in losses for each of the three income classes, except for Full Auto 60, where the upper income class gained. Upper income travelers consume more auto travel and have a higher value of time than do the other two groups and so benefit when the other groups do not. HOV caused small losses for all income classes and LRT brought about small gains for all groups. The pricing sensitivity-test scenarios brought about large overall welfare gains, as theory predicts (about $0.25 per trip), but losses for the lower income group, due to their low value of time.

6. Conclusions Regarding AHS

We believe that this travel model produced reasonable results overall and, specifically, represented induced tripmaking and longer trips reliably. It seems that the consumer welfare model also produced reasonable results.

In our subsequent research, though, we wanted to do a more complete welfare analysis that included capital and O&M costs for the ITS scenarios. This next modeling improvement was made in a study of advanced transit scenarios, again for the Sacramento region.

D. Modeling Advanced Transit Technologies

1. Literature Review

Introduction

In this research, we focused on a subarea of ITS technologies: improved and/or new transit services that make use of information and automation technologies. These transit technologies include advanced transit information (ATI), demand responsive transit (DRT), and personal rapid transit (PRT). We examine the travel, emissions, and consumer welfare effects of these ITS technologies.

Whereas accurate modeling of AHS requires the representation of induced travel, the accurate modeling of ITS transit technologies requires models with good mode choice submodels. The walk and bike modes must be explicitly modeled, as well as the auto 2 and auto 3+ carpool modes, because these modes compete with transit. Furthermore, transit access modes, such as walk to transit and drive to transit, must be represented as separate modes. It is also advisable to represent land use density and mix near transit lines in the transit mode choice equations, as land use can affect ridership on transit, as well as walk and bike mode shares.

Advanced Transit Information

Advanced transit information technologies would provide travelers with information about available transit service before and during their trip. Travelers can access this information at home, work, transportation centers, wayside stops, and while onboard vehicles through a variety of media such as telephones, monitors, cable television, variable message signs, kiosks, and personal computers. Some systems with links to automatic vehicle location are beginning to be able to provide real-time information about available transit service, such as arrival times, departure times, and delays. There are three types of transit information systems: (1) pre-trip, (2) in-terminal, and (3) in-vehicle [21]. In this paper, we focus on pre-trip advanced transit information systems.

Pre-trip service that provides travelers with accurate and timely information about transit travel may increase travelers' awareness of available transit service and reduce some of the uncertainty surrounding transit use. For some trips, the combination of these two factors may make travel by transit more appealing than traveling by car. Pre-trip information can include transit routes, schedules, fares, and locations of park and ride lots.

Few studies have examined the effect of transit information systems on traveler's choice of mode. One study [22], for example, examined travelers' preferences for different types of travel information and methods of inquiry, as well as the effects of travel information on travel behavior. The study made use of a stated preference survey of individuals who used in-home computers that provided pre-trip information on bus and car travel times from home to the city. The results of the study indicated that there was a significant demand for both auto and transit pre-trip information, even among regular car users.

Another study [23] used computer aided telephone interviews in the Sacramento and San Jose areas of California to identify the transit service information most desired by non-transit users. In addition, customized stated preference choice sets were used to identify the likelihood of a commuter's choice to use transit. The study found that 38 percent of the respondents who did not use transit would likely consider using transit if improved information were provided. Such variables as travel time, carpooling, and age were found to have a significant effect on the propensity to use transit.

Shank and Roberts [24] in their review of ITS benefits found that traveler information technologies may result in shifts from the auto to transit mode; however, resulting emissions benefits may be small. They cite surveys performed in the Seattle, Washington area and the Boston, Massachusetts area that found a five to ten percent increase in the transit mode when traveler information was provided. However, they estimated that even with sizable mode shifts from auto to transit, reductions in emissions would be still be comparatively small due to the relatively small number of total trips affected by the shift.

Paratransit and Demand Responsive Transit

Cervero [25] describes paratransit as transportation options that range from the private automobile to fixed-route bus service. "Paratransit fills an important market niche: like autos, they are flexible and fairly ubiquitous, connecting multiple places within a region, but at a price far below a taxi" [25]. Paratransit service was originally implemented in the U.S. in the 1970s. Over the years, paratransit has changed a great deal. However, today most paratransit service can be characterized as either low-tech or high-tech service [26].

We define demand responsive transit in this report as a subset of paratransit that uses automation and information technology to improve traditional paratransit service. Thus, demand responsive transit would be considered high-tech paratransit service.

Low-tech paratransit includes dial-a-ride, shared-ride taxis, and airport van services. The shared ride nature of these services makes scheduling more complex than taxi dispatching. The special needs of elderly and disabled passengers, who frequently use paratransit, can also complicate scheduling further. Today, many paratransit operators have computerized scheduling processes.

In high-tech, or smart paratransit, computers are used to satisfy real-time trip requests by predicting the approximate location of vehicles during a daily schedule that is retained in the computer's memory. If a new trip is requested, the computer will revise the schedule and transmit it to the driver so that she can pick up the new passenger. In practice, real time scheduling of paratransit has only been implemented in demonstration projects in the 1970s; the sole surviving service is in Orange County, California. Today, "Orange County operates the largest publicly owned dial-a-ride van service in the country, serving mainly elderly and poor households with some 125 vans on a contract basis" [25].

A number of studies [27,25,28,29,30] have examined the question of how to expand the target market for paratransit services beyond the traditional users through services catering to the average commuter, such as demand responsive transit that feeds to light rail systems [26]. However, few studies have examined quantitatively the effect of providing paratransit service on the mode choice behavior of travelers.

One study [28] explored Honolulu commuters' interest in a number of different transportation modes. It found that paratransit with improved service was the most widely accepted of all transit modes. The major causal factor behind this result was the combination of reduced access by auto, due to congestion, and a guaranteed seat in the paratransit vehicle. The study also suggested that paratransit is capable of attracting the commuters most resistant to changing travel modes.

Another study [31] provided a framework for examining the effect of various levels of paratransit service on ridership. Revealed preference and stated preference survey data were combined to avoid the biases of stated preference surveys. They found a positive correlation between the levels of paratransit service and ridership levels. They also found that age, difficulties in walking, and employment status were important factors in choosing to ride paratransit.

Personal Rapid Transit

Personal rapid transit (PRT) is a subset of Automated People Movers (APM). In this paper, the we differentiate PRT from APM by the number of passengers that the vehicles carry. APM vehicles generally carry 12 to 100 passengers, whereas PRT vehicles generally carry from 1 to 6 passengers. There are no true PRT systems in operation in the U.S. today (the Morgantown, West Virginia, PRT system accommodates 21 people in a vehicle). However, the Northeastern Illinois Regional Transportation Authority is funding a PRT project in Rosemont, Illinois, that is still in the testing stage.

APMs are a system of steel or concrete exclusive guideways with small, driverless, electric-powered vehicles that are generally operated singly or in multi-car trains. APMs can accommodate from 2,000 to 25,000 passengers per hour per direction. The headways for APMs can be very short (e.g., 60 seconds, or even less for smaller systems). APMs operate at high speeds (e.g., 55 mph) and accelerate and decelerate rapidly and smoothly. The safety and reliability of the SkyTrain APM system in Vancouver, Canada, and the VAL APM system in Lille, France, have been documented as excellent; over 99% of runs are on-time within 4 minutes and zero injuries or fatalities have been reported [32].

2. Advanced Transit Scenarios Modeled

We will describe these scenarios in some detail, as the differences among them are much smaller than in the study of automated freeways, and so distinguishing among them is more difficult. Five advanced transit scenarios in the Sacramento region for the year 2015 were examined. SACOG provided the demographic projections and networks. The networks include transportation projects listed in SACOG's 1996 Metropolitan Transportation Plan Working Paper #3 (MTP). All changes to the input data and model codes are described for each alternative below. The SACMET 95 model was used, but this model is very similar to the SACMET 94 model described above. To project social welfare, we added the capital and O&M costs of each scenario to that scenario's consumer benefits. We did not have reliable external cost data and so did not perform a complete social welfare evaluation.

a. 2015 Base Case Scenario

The future base case scenario includes modest light rail transit extensions east to Mather Field and south to Meadowview road, as well as modest land use projection shifts in some areas of the region. This scenario also includes some ramp meters on freeways and a conservative number of new roadway projects. New HOV lanes are excluded from this scenario and no new mixed flow freeway lanes are built. This base case is used for comparison purposes; that is, all improvements are added to this scenario.

All network and land use modeling files were obtained from SACOG's "Transportation Management/Land Use Option" alternative [33]. The changes made to these files for our base case scenario were (1) to eliminate all HOV lanes from the roadway network and (2) to eliminate the demand responsive transit from the transit network.

b. Advance Transit Information (ATI) System

Transit users access real time transit scheduling information through 100 kiosks located at transit stations and workplaces, the telephone, the Internet, and cable television. This scenario assumes the broad dissemination of personal digital systems.The maximum initial wait times for all transit service in the model were reduced to three minutes.

c. Personal Rapid Transit (PRT)

Systems of exclusive, fairly short guideways and small, driverless vehicles are constructed to link nine regional transit stations to important locations close to these stations. PRT service has one minute headways and a fare of fifty cents.

PRT is coded in the transit network file as a new transit only route with direct routes between RT stations and proposed locations with short wait times. Headways are coded as one minute.

d. Demand Responsive Transit

Demand responsive transit service is provided to connect people in nine inner suburban areas to light rail transit stations. Initial boarding fares are $1.25 and transfers to light rail are $0.75. Headways for demand responsive transit range from fifteen to thirty minutes. This scenario also expanded bus service in El Dorado county.

The demand responsive transit files from SACOG's "Transportation Management/Land Use Option" alternative [33] were added to the base case scenario files to create this scenario. SACOG coded the demand responsive transit in the transit network file as new transit only routes with short direct routes between zones and LRT station locations with short wait times.

e. Combinations of Scenarios

The advanced transit technologies described above were combined into the following five scenarios.

1. Base Case
2. Advanced Traveler Information
3. Advanced Traveler Information and Personal Rapid Transit
4. Advanced Travel Information and Demand Responsive Transit
5. Advanced Traveler Information, Personal Rapid Transit, and Demand Responsive Transit

3. ITS Transit Findings and Discussion

Travel Results

All of the advanced transit scenarios produced relatively small reductions in trips, VMT, hours of delay, and total hours of travel over the base case scenario. Differences were less than 0.5% for all measures, except for hours of delay, which differed by less than 2%. Thus, it appears that the advanced transit scenarios modeled in this study will not provide significant relief from traffic congestion and are unlikely to reduce travel enough to provide significant emissions reductions.

The differences between pairs of the advanced transit scenarios modeled was quite small. In general, the small differences between scenarios suggests that the model represents limited synergism resulting from the combination of different advanced transit service alternatives due to overlapping markets in a region with poor transit service in general.

All of the advanced transit scenarios resulted in significant relative increases in transit with walk access and transit with drive access mode shares over the base case scenario. The transit with walk access mode share increased by approximately 64% to 92%, and the transit with drive access shares increased by approximately 37% to 41%. Again, the addition of an advanced transit service in the scenario increased the transit mode share; however, differences among scenarios were generally small.

Much of the gain in the transit mode shares appears to be derived from losses in the walk, bike, and HOV mode shares, rather than the drive alone mode share. The smallest reduction in mode share as a percentage comes from the drive alone mode share; however, with respect to the absolute numbers of trips, the reduction in drive alone mode share was the greatest. Combined transit mode share for the region reached its highest level at 1.48% for the ATI, DRT, and PRT scenario (the future base case figure is 0.81%).

These results suggest that the time and monetary costs of transit travel in the advanced transit scenarios are not competitive with those of the drive alone mode, for the great majority of households. Relatively small reductions in auto travel from the base case scenario are likely the result of a number of factors. First, the transit travel time savings were not large enough to compete with the auto mode, despite the innovative transit policies modeled. Second, the scope of the transit network is very limited in the Sacramento region, and thus the effectiveness of any improvement in transit feeder service is limited. Third, as mentioned in the methods section, the propensity for auto drivers to switch to transit modes in the presence of lower transit travel time and costs is likely underrepresented in the SACMET 95 model. This is an artifact of the cross-sectional data used to estimate the model. Sacramento currently has minimal transit service and comparatively low land use densities (compared to urban areas with high transit use), and thus cross sectional data on travel behavior collected in this area would contain little variation in transit mode choice. Finally, comfort, reliability, and security have been shown to be significant variables in the choice to use transit. These variables are not explicitly included in the SACMET 95 model because they are very difficult to project into the future. Generally, such attributes are included in the mode specific constant of the mode choice models in regional travel demand models.

Emissions

In general, the reductions in emissions are small and consistent with the VMT differences. The scenarios differ from the base case by less than 0.5% for all pollutants. Again, the differences among scenarios are small. In general, it appears that the advanced transit scenarios modeled in this study will not result in significant reductions in emissions.

Total Consumer Welfare

The benefits from the 2015 scenarios (in 1995 dollars) were discounted back 20 years using the present value formula and the real discount rate of 6.25%:

$$PV\ 1995 = 2015\ \text{Scenario Benefit in}\ \$1995/(1.0625)^{20}$$

The projections for the 1995 present value of total consumer welfare without capital, operation, and maintenance costs are quite close ($0.014-$0.017 per trip). All of the scenarios produced an increase in total consumer welfare because of the faster transit travel times. However, the differences between the scenarios are small for the same reasons discussed above.

Capital, operation, and maintenance cost figures for advanced transit information technology are based on estimates from the SMART TRAVELER project in Los Angeles. Cost figures for DRT are based on interviews with managers at the Santa Clara Valley Transportation Agency and Sacramento Paratransit and on the Lea & Elliott Transit Compendium [34]. Cost figures for PRT are based on information from system developers whose systems can be considered to be in an advanced state of development, including the Raytheon 2000, Taxi 2000, and Yeoida systems. Table 1 presents our estimates of the 1995 present value of capital, operation, and maintenance costs that would be incurred in the year 2015.

Table 1. 1995 Present Value of Capital, Operation, and Maintenance Costs.

Scenarios	Total Capital Costs	Annual Capital Costs (incurred in 2015)	Scenarios	Daily Total Including O & M Costs (incurred in 2015)
ATI	$563,889	$22,926	ATI	$1,392
DRT	$4,215,637	$171,395	ATI & DRT	$23,572
PRT	$112,447,930	$4,571,803	ATI & PRT	$18,286
DRT& PRT	$116,663,567	$4,743,199	ATI, DRT & PRT	$54,140

The 1995 present value figures for total consumer welfare including capital, operation, and maintenance costs for the 2015 advanced transit scenarios are very similar ($0.009-$0.015 per trip). These figures were obtained by subtracting the 1995 present value of the daily cost of the capital, operation, and maintenance costs from the 1995 present value of the daily welfare benefits.

With the inclusion of capital, operation, and maintenance costs, there is still a consumer welfare gain for all the advanced transit scenarios; however, the rank ordering of the scenarios is altered. ATI service alone produces the greatest increase in consumer welfare ($0.015 per trip); that is, the addition of DRT and PRT service to the ATI scenario tends to reduce consumer welfare. On average the addition of DRT service to the ATI scenario decreased per trip benefits by $0.002, the addition of PRT service decreased per trip benefits by $0.004, and the addition of both DRT and PRT service decrease per trip benefits by $0.006. These results are due to the low costs and high travel time savings of ATI service in comparison to DRT and PRT service; the time savings estimated in the model from DRT and PRT service do not appear to be great enough to offset their capital costs. DRT and PRT service, however, could possibly be adjusted to obtain a better balance between time savings to travelers and the cost of service provided.

Consumer Welfare by Income Class

The 1995 present value figures for consumer welfare by income class without capital, operation, and maintenance costs vary by income class, as expected. The net benefits for the lower income group are \$0.008-\$0.009 per trip, the middle income group net benefits are \$0.016-\$0.018, and the high income group's net benefits are \$0.013-\$0.017 per trip. All of the scenarios result in an increase in consumer welfare to each income class; however, the lowest income class benefits least, absolutely. Lower income classes have a lower value of time, and thus the savings in transit travel time are valued less for this class than for the other classes. The highest income class tends to benefit less on average per trip than the middle income class. Income class three has a higher value of travel time than income class two; however, their lower average or equal consumer welfare for the scenario may be due to the fact that this class received less advanced transit service near their work or home locations. In general, the differences among the benefits of the three income classes are relatively small. Nevertheless, the fact that these scenarios are not regressive is important, politically.

The results of the analysis of consumer welfare by income class that includes capital, operation, and maintenance costs (1995 present value) are similar. These figures were obtained by subtracting the 1995 present value of the daily cost of the capital, operation, and maintenance costs incurred by each income class from the 1995 present value of the daily welfare benefits received by each income class. Capital, operation, and maintenance costs of the technologies are assumed to be borne by individuals in proportion to their amount of travel.

With the inclusion of capital, operation, and maintenance costs, the distribution of benefits across the three income classes did not significantly change. The net benefits per trip are: Lower income ($0.000-$0.008), middle income ($0.010-$0.016), and higher income ($0.009-$0.015). This result is to be expected, given our assumption regarding the distribution of costs. An accurate equity analysis requires that we assume one or more methods of payment for these facilities and estimate the payments by income group (Federal and State income taxes, local sales and property taxes). Actual methods of payment, of course, vary across regions and over time within regions and so are impossible to project, except by assumption. These scenarios appear to be not regressive, given these cost assumptions, though.

4. Conclusions of the ITS Advanced Transit Technologies Study

The analyses provided in the previous section allow for a number of general conclusions to be drawn in this study.

1. In regions like Sacramento that lack extensive penetration of rail or line-haul transit service, advanced transit technologies that act as feeder service may not significantly reduce congestion and emissions.
2. In general, the advanced traveler information and demand responsive transit technologies modeled seemed to provide greater reductions in congestion and emissions than personal rapid transit technology.
3. Combining the modeled advanced transit technologies did not tend to increase the travel and emission benefits by a significant amount over the individual technologies because of overlapping markets in a region with limited light rail service.
4. When capital, operation, and maintenance costs of the advanced transit technologies were not included in consumer welfare estimates, total welfare increased by approximately 1.4 to 1.7 cents per trip (in 1995 present value) across scenarios for all trips in the region.
5. When capital, operation, and maintenance costs of the advanced transit

technologies were included in consumer welfare estimates, the advanced transit information scenario yielded a higher consumer welfare benefit (1.5 cents per trip in 1995 present value) than the scenarios that added demand responsive transit and personal rapid transit (from 0.9 to 1.3 cents per trip in 1995 present value). These differences are certainly within modeling uncertainty, however.

6. The lowest income class in the region generally received lower net benefits per trip, absolutely, than did the other two income classes, but never sustained a loss.

The travel and emissions results in this study showed that the advanced transit technology scenarios have little impact on travel and emissions in this region. As a result, decision makers would not know whether to adopt them. The consumer welfare evaluation, however, showed that all the advanced transit technology scenarios were beneficial and generally equitable, even when capital, operation, and maintenance costs were included in the analysis. The analysis also showed that advanced transit information service alone produced the greatest increase in consumer welfare; that is, the addition of demand responsive transit and personal rapid transit service to the advanced transit information scenario tended to reduce consumer welfare benefits. Thus, we conclude that the method of obtaining consumer welfare used in this study is a useful analytical tool for identifying optimal bundles of ITS technologies.

E. Overall Conclusions and Future Research Directions

Conclusions

1. The evaluation of AHS requires travel demand models that represent all forms of induced travel. In addition some method of modeling changes in land use patterns must be used, whether through expert consensus or by using formal models. No one has simulated the effects of AHS on land markets, but several models are available that can do this.

2. Accurate evaluation of ITS transit scenarios poses other requirements. Travel models must have sophisticated mode choice submodels with the bike and walk modes represented and

with transit access modes separately modeled. Regions with large carpool shares should represent auto 2 and auto 3+ in the mode choice submodel. An HOV lane use model will probably increase the accuracy of carpool mode projections. Last, it seems wise to include land use variables in the auto ownership equations and in the transit mode choice equations, to account for these influences.

3. The evaluation of any type of ITS technology requires the development and application of user welfare models and, hopefully, social welfare models. Utility-based models are easy to use in regions with logit mode choice submodels. In other regions, the cost-based method of user welfare evaluation can be used. Full social welfare evaluations will be possible soon, because USDOT is completing a large external costs study this year.

4. Regarding our specific research experiences, we conclude that advanced travel demand models such as we used are adequate for evaluating AHS and ITS transit scenarios and that a utility based traveler welfare model is easily adapted for use with such a travel model. Our findings on the travel and emissions effects and on the economic effects of the scenarios evaluated seems reasonable, judged against theory and limited empirical experience. Current law in the U.S. seems to require these, or similar, methods.

Future Research Directions

1. Our group is proceeding to refine the modeling of AHS by calibrating the most tractable of the two integrated, market-based urban models available, the Tranus model, on Sacramento region datasets. Our initial calibration on 1990 datasets seems adequate and we are now going to perform a dual calibration on 1980 and 1990 data. We will also add in commercial vehicles and refine our transit and land consumption elasticities. We will then model AHS, along with other conventional scenarios, and project the effects on travel, emissions, energy use, and locator welfare. We can get emissions directly by applying the California emissions models to our link-based vehicle activity data or we can output the Tranus land use projections into the

SACMET 95 model zone files and run it.

2. We are also proceeding to improve our economic welfare model by adding capital and O&M costs for all AHS and other scenarios and by adding in external costs per person-mile. The USDOT external cost figures for auto travel are available in draft form and the data for the other modes will be available soon.

3. Another improvement will be better modal emissions data for autos in AHS platoons. These research projects are going on now and so these data will be available in the next few years. The requisite microsimulation travel demand models, that can represent individual vehicles, are also under development, in California and in national programs.

4. One could combine these various models, so each can do what it does best. For example, an integrated urban model could be used to capture the land use effects of AHS on the urban edge or of major ITS transit improvements near to rail stations. These land use data could then be fed to travel models, which would then project emissions. When the microsimulation models are available, they could replace the current travel models.

5. If one wished to also model the purchasing of clean-fuel vehicles, household vehicle transactions models are under development now and will soon be in use in California. These models project the effects on vehicle purchases of various pricing schemes applied at the retail level and of regulatory policies applied to the manufacturers. Then, the travel demand or microsimulation travel models could account for the new fleet composition projected by the vehicle transactions models.

So, the ITS modeling problems that seemed so formidable only a few years ago are rapidly being overcome. Soon, we will be able to determine which of these ITS technologies are worth implementing in each urban region.

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