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TRAVEL MODELING WITH AND WITHOUT FEEDBACK TO TRIP DISTRIBUTION

By Robert A. Johnston[1] and Raju Ceerla[2]

(Reviewed by the Urban Transportation Division)

ABSTRACT: Many regional agencies model travel demand without feeding assigned travel times back to the trip distribution step. This method saves time and money but is likely to be biased in favor of build alternatives because it would underproject trip lengthening induced by the added capacity. Emissions and travel costs for the new roadway projects would be consequently underprojected. We wanted to compare outcomes under the two simulation methods. Our methods of modeling travel demand are outlined and then the results are presented and discussed. With full feedback, building new freeway carpool lanes appears less favorable than doing nothing or than expanding light-rail transit, in terms of induced travel. Light-rail–system expansion has lower emissions than does building new carpool lanes, with partial feedback, and full feedback increases these differences substantially. Better modeling methods, to be used in extensions of this research, are outlined.

PURPOSE AND OBJECTIVES

This study was undertaken for Caltrans in order to simulate the travel and emissions impacts of urban freeway automation scenarios and to compare these to travel demand management (TDM) scenarios, such as travel pricing and land-use intensification. We operate the Sacramento regional travel demand model set in our lab. The accurate evaluation of new freeway capacity is important for this region for three reasons: (1) a system of new high-occupancy vehicle (HOV) freeway lanes is an adopted policy; (2) this region has the highest percentage of hydrocarbons (VOC) from mobile sources of any large urban region in the United States; and (3) the region has been under a court order from a lawsuit under the federal Clean Air Act.

We operate the model set in two ways. The first protocol is with the use of free-flow speeds in trip distribution and the feedback of zone-to-zone travel times from assignment back to just the mode-choice step, the conventional method used in this region. Second, we iterate the model set with the feedback of assigned travel times to both the trip distribution and mode-choice steps. We iterate until we can estimate the equilibrium output values for vehicle miles traveled (VMT), vehicle hours traveled (VHT), and the other demand measures by averaging the converging outputs. We do not adjust link speeds to observed speeds with either method. These travel data are then fed into the official California emissions models.

The adopted Environmental Protection Agency (EPA) procedures for transportation conformity analysis now require (for serious, severe, and extreme ozone nonattainment areas) that travel times from assignment agree substantially with those used in distribution, beginning in 1995 [40 CFR Part 51, section 51.452 (b)(1)]. Legally, this issue has been settled, but it is still useful to see how such a methodological change affects projections in an actual region, because such an analysis illustrates the reordering of projects that may have to occur in some areas. We are not aware of past research that compares the projections from models operated in both ways.

METHODS

The travel demand models used were those developed by Sacramento Regional Transit for its 1988 Systems Planning Study. The trip generation model was based on the 1968 Sacramento (Calif.) Area Transportation Study that was developed from a 1968 household survey data set. Changes were made to the production rates, based on recent rates for similar urban regions. Then the trip production rates were recalibrated (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 were not modeled ("Sacramento" 1990, 1991).

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 (*MINUTP* 1991). The friction factors were based on those used in the Seattle 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.

New mode-choice models were developed for the 1989 Systems Planning Study based on the 1989 Regional Transit ridership and on-board surveys. Mode-choice models were developed for two sets of trip purposes, home-based work trips and nonwork 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." Midrange values from models of other urban areas were used for the level of service (time, cost) coefficients ("Sacramento" 1990). Insofar as these other models were discrete-choice, household-based utility models, such transference is arguably acceptable. Mode-specific constants and coefficients for transit access came from validation against local onboard survey data. Explanatory variables included in-vehicle time, walk time, wait time, transfer time, auto access time, auto operating cost/(occupancy × income), parking cost/(occupancy × income) by destination zone, transit fare/income, central business district (CBD) location or not, and number of autos in the household.

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

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factored for origin-destination distances, auto ownership, and trip purpose.

Capacity-constrained equilibrium assignment is used for roadways.

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.

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 speed 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 in our modeling process. This is a crude method, but one of the methods known to work (Boyce et al. 1994).

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 and VHT 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 and VHT 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 towards equilibrium. We also inspected the VMT × 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 8–16 km/h (5–10 mi/h), 16–24 km/h (10–15 mi/h) and 24–32 km/h (15–20 mi/h) classes varied regularly, inversely to total VMT and dampened. The VMT for the speed classes for 80–89 km/h (50–55 mi/h), 89–97 km/h (55–60 mi/h) and 97–105 km/h (60–65 mi/h) 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 kilometer 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 CBD 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 of trip-generation rates) would not change the rank orderings of our projections.

Alternatives Modeled

Existing alternatives included

1. 1989 base year
2. 2010 no-build (modeled with year 2010 predicted land-use data without any major transportation facility improvements)
3. HOV lanes [a system of existing and proposed new HOV lanes on the inner freeways by the year 2010 (150 lane-km or 93 lane-mi)]
4. Light-rail transit [alternative 8 of the systems planning study (44 stations)]

Automation alternatives included

1. Automation 1—partial automation of the freeway links using the year 2010 no-build alternative. Only the freeway links that had a level of service of F were automated and they were set to 97 km/h (60 mi/h) and 1-s headways (i.e., 3,600 vehicles/hour/lane capacity). Only one lane in each direction on most of the inner freeway network needed to be automated.
2. Automation 2—in this scenario all the urban area freeway links were automated and set to a speed of 97 km/h (60 mi/h) with 1-s headways. All capacity changes were made for the appropriate facilities.
3. HOV1—in this case only the HOV lanes are automated and set to 97 km/h (60 mi/h) with a 1-s headway. All other input files are the same ones used for the HOV scenario. In all three automation scenarios, it was assumed that all vehicles were equipped for automated operation.

In all cases the speed/flow characteristics were adjusted where necessary to reflect the changes in the volume/capacity ratio.

The land-use intensification alternatives and the pricing alternatives were based on the light-rail transit (LRT) alternative. The land-use (housing and employment) and zone characteristics (accessibility index) data sets were changed for the land-use alternatives. For the pricing alternatives the zone characteristics (zonal parking costs) data set was altered. All other input data sets were kept the same as for the LRT. The following describes the three TDM alternatives modeled:

1. LRT + pricing. Auto travel pricing, parking cost increases, and a gas tax increase were added to the LRT alternative.
2. Transit-oriented development (TOD). 2010 land-use growth was moved from the fringe areas and areas far from light-rail stations into the existing and proposed light-rail station locations.
3. TOD + pricing. Pricing was combined with the TOD land uses.

The modeling process for the pricing scenarios was based on three travel-cost increases. The auto-operating cost was increased by 1.9 cents/km (3 cents/mi) to reflect an increase in gasoline taxes of $0.60/gal. The auto travel pricing was placed at 19 cents/km (30 cents/mi) for all trips on all facilities. We did not use congestion (peak-hour) pricing, because our trials with it produced higher levels of VMT. Parking costs were increased to $5.00 per trip in the CBD, $3.00 at other major employment centers, and $2.00 at all other places.

The TOD alternatives involved the use of the LRT network ut with considerable changes to the 2010 land-use data. Landse intensification was done around existing and proposed ight-rail stations within a 400 m (0.25 mi) radius, generally, nd up to 800 m (0.5 mi) if necessitated by the zone boundries.

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

FINDINGS AND DISCUSSION

Travel Demand

The two protocols used were the "feedback to mode choice only" (partial feedback) runs and the "feedback to mode choice and trip distribution" (full feedback) runs (Table 1). The VMT for each alternative was reduced considerably in the full feedback runs, but by varying degrees for each of the alternatives studied. This is primarily the result of the varying effect of congested speeds on the systemwide performance of the different alternatives in the trip-distribution step. The vehicle-hours of delay (VHD) projections are reduced by even greater percentages, as expected, since congestion increases nonlinearly with volumes as link volumes approach link capacities.

With partial feedback, the no-build scenario has a higher VMT than do the two actual policies adopted in the region, LRT expansion and new HOV lanes. With full feedback, however, the no-build alternative has lower VMT than the HOV alternative, more correctly accounting for the travel induced by the new HOV lanes. Under partial feedback HOV has only slightly higher VMT than does LRT, whereas with full feedback HOV has much higher VMT than does LRT. These findings are potentially significant, because many nonattainment regions are planning large systems of new HOV lanes.

Concerning freeway automation, which is a major emphasis of the surface transportation act, with partial feedback automated HOV lanes have less VMT than no build, whereas with full feedback automated HOV lanes have more VMT than no build. These VMT rankings directly affect acceptability in California, which requires substantial reductions in the rate of growth of trips and of trip lengths in nonattainment areas.

Concerning the TDM policies, the lowest VMT ones under partial feedback are TOD with pricing and then LRT with pricing. This model operation protocol emphasizes the effects of prices on travel (in mode choice). With full feedback, the lowest VMT alternatives are the two TOD policies, then the two LRT scenarios, and then no build. Full feedback simulates the effects of both pricing and congestion on travel. Operating the model set with partial feedback overemphasizes the travel-reduction benefits of pricing measures.

TABLE 1. Summary of Travel Results with Full and Partial Feedback

Scenario (1)	Full Feedback VMT (M) (2)	Full Feedback VHD (K) (3)	Full Feedback TRST (%) (4)	Partial Feedback VMT (M) (5)	Partial Feedback VHD (K) (6)	Partial Feedback TRST (%) (7)
No build	49.28	349.9	1.08	55.93	692.0	1.05
HOV	51.09	320.3	1.68	55.75	522.7	1.67
LRT	48.97	387.0	1.82	55.53	648.0	1.90
LRT + 30 cents/mi	48.14	249.3	3.50	52.07	403.7	3.60
TOD	46.81	334.0	2.18	53.40	645.6	2.32
TOD + 30 cents/mi	45.83	306.7	2.34	51.78	591.7	2.55
Auto partial	52.68	280.0	0.86	59.42	461.0	1.00
Auto full 60 mi/h	51.61	321.0	1.05	59.11	597.0	1.00
HOV1 60 mi/h	52.51	356.3	1.70	55.53	479.4	1.69

Note: VMT = vehicle miles traveled; VHD = vehicle hours of delay; TRST = transit trips; KMT = 1.61 (VMT).

The most important substantive finding is that doing nothing (no build) may not be so bad, in terms of VMT and even VHD, when evaluated properly. Many economists recommend not adding freeway capacity in urban regions in the United States, arguing that auto travel is subsidized and that congestion is self-limiting as people move closer to their jobs.

Note that congestion hours (VHD) are cut by 33–49% for all the scenarios when full feedback is used. State and national congestion projections are based on the partial feedback method used in most regions and so are exaggerated.

Table 1 also shows the percent of trips on transit. In general, the higher VMT scenarios have the lower transit ridership. An exception is automated HOV lanes, where transit ridership is higher than no build and the same as HOV. With bus times determined partially by roadway speeds, some forms of auto capacity increase, especially HOV lanes, can speed up buses. In our simulations, the buses travel at the same speed as the autos (60 mi/h) in the automated HOV lanes. Buses could well be automated, of course, since that would be more cost-effective than automating autos.

Another seeming anomaly is that LRT + 30 cents has higher transit ridership than TOD + 30 cents. We believe this to be due to slower surface roadway speeds in the TOD zones, because of the higher land-use densities, in turn slowing down drive-to-transit travelers. One could reduce this problem by pulling parking off of some arterials, at least during peak periods, or by creating bus-only lanes leading to the rail stations. Mode-choice models with walk and bike modes might well project less drive-to-transit and more walk- and bike-to-transit. The overall finding here is that it takes heroic land-use and/or pricing measures to merely double transit ridership (the base year share is 1.41%).

A better model set with accessibility feedback to auto ownership and trip generation, however, would presumably show greater VMT differences in tests such as these. Nevertheless, the model runs reported here tentatively indicate that feedback to trip distribution can affect the rankings of alternatives, even of conventional ones (no build, HOV, LRT). This methodological result is very significant for MPOs, since they must reduce mobile emissions and will be required to use full feedback, beginning in 1995.

Emissions

In spite of the changes in rank ordering of the scenarios in terms of VMT under the two modeling protocols, the emissions rankings among groups of scenarios do not change. Looking at Tables 2 and 3, we can see that auto HOV 60 is the worst in terms of ROG and CO emissions under both feedback methods. As a group, the automation scenarios are worst, using either travel-demand modeling method.

The two LRT scenarios and the two TOD ones are best for TOG and CO, under both methods. TOD with 30 cents is the lowest for TOG, modeled both ways.

The emissions rankings of the conventional build alternatives also do not change when the two feedback methods are compared. The LRT scenario remains lower in emissions than HOV lanes and HOV lanes are lower than the no-build case. The main difference with policy significance is that with full feedback the HOV scenario is barely superior to the no-build case for CO. Also, LRT is much better than HOV for both ROG and CO, compared to the partial feedback runs. LRT's

TABLE 2. Sacramento Region Vehicle Emissions (Tons)—Feedback to Mode Choice Only (Summer/Ozone Planning Inventory)

Pollutant (1)	1989 base (2)	2010 no-build (3)	HOV (4)	LRT alt 8 (5)	LRT with 30 cents/mi (6)	TOD (7)	TOD with 30 cents/mi (8)	Automation partial (9)	Automation 60 mi/h (10)	HOV auto 60 (11)
TOG	38.75	20.55	19.63	19.13	18.82	18.84	18.78	21.00	20.73	21.13
CO	524.13	324.56	320.96	309.60	302.33	304.86	302.40	332.45	329.10	348.36
NOx	47.89	49.05	51.26	48.58	47.33	47.47	47.21	50.14	54.31	57.22
Fuel	0.78	2.44	2.42	2.31	2.24	2.25	2.24	2.57	2.72	2.74
Evap.	21.84	3.98	3.95	3.99	3.95	4.01	3.98	4.09	3.98	3.96

Note: Vehicle emissions are based on impact rates from EMFAC7EPSCF2.

TABLE 3. Sacramento Region Vehicle Emissions (Tons)—Feedback to Trip Distribution and Mode Choice (Summer/Ozone Plannin Inventory)

Pollutant (1)	1989 base (2)	2010 no-build (3)	HOV (4)	LRT alt 8 (5)	LRT with 30 cents/mi (6)	TOD (7)	TOD with 30 cents/mi (8)	Automation partial (9)	Automation 60 mi/h (10)	HOV auto 60 (11)
TOG	37.85	19.53	18.73	17.54	17.32	17.31	17.22	19.77	19.89	20.28
CO	504.56	306.35	305.17	280.65	273.52	276.73	274.37	313.73	315.1	333.54
NOx	45.57	45.72	48.19	42.79	41.53	41.67	41.44	47.15	51.34	54.09
Fuel	0.73	2.25	2.26	2.01	2.30	1.95	1.94	2.36	2.55	2.57
Evap.	21.78	3.87	3.88	3.87	3.87	3.88	3.87	4.03	3.96	3.95

Note: Vehicle emissions are based on impact rates from EMFAC7EPSCF2.

advantage over HOV lanes in terms of lower NOX is also increased under full feedback. Full feedback makes building new HOV lanes come out worse, because of the added VMT. Small differences in our emissions projections should be viewed with care, however, because of the inaccuracies of the travel modeling, combined with the inaccuracies of the emissions models themselves.

The emissions projections do not exhibit the sensitivity to modeling methods as much as do the travel-demand projections. Full feedback compresses the VMT differences and changes some VMT rankings, whereas the emissions modeling based on the two data sets compensates for some of the differences, because of the resulting distribution of VMT by speed class.

We will replicate these tests with the new regional model set in late 1994. That set will include a new auto ownership model, walk and bike modes, separately calibrated peak and nonpeak models, and better link capacity data to improve speed projections. Also, we will use the new California EMFAC7F emission factors, which have higher emission rates for very low and for high speeds.

CONCLUSIONS

The full-feedback process has a significant effect on VMT and congestion delay rankings. With typical current modeling practice, VHD is substantially overprojected. This would have a great impact on how we interpret the environmental impacts of certain congestion mitigation measures using regional models. Also, federal and state transit funding agencies may wish to require the use of full-feedback modeling protocols, to more accurately simulate travel effects and financial and economic effects of proposed projects. The free-flow speed/partial feedback method was used in this region in a study of new rail lines. Likewise, state air-quality agencies may wish to require the full-feedback method, so as to more accurately project emissions under state clean air law.

In terms of practical policies in the region, the policy of building new HOV lanes comes out much worse when modeled in a more accurate fashion, since it adds the most auto capacity. Full feedback makes LRT and no build have lower VMT than new HOV lanes, whereas under partial feedback they are roughly equal.

The most interesting substantive result specific to the region, under full feedback, is that doing nothing looks better and even appears to be superior to HOV lanes in terms of VMT and NOX, and almost equal on CO emissions. The modeled advantage of light-rail expansion, in terms of all types of emissions, increased with full feedback. These are important issues in this region and in many other urban areas in the United States, for both project evaluation under the surface transportation act and also for air-quality conformity analyses.

The clearest conclusion, however, is that models such as these 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, cannot feel comfortable with models that omit several classes of behavior entirely.

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