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Simulated Travel Impacts of High-Occupancy Vehicle Lane Conversion Alternatives

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A simulation model of a hypothetical highway corridor was used to analyze the effects of converting an existing high-occupancy vehicle (HOV) lane to either a high-occupancy toll (HOT) lane or a mixed-flow lane. The simulation model, which uses a nested logit structure with a synthetic sample of individuals, estimates vehicle miles of travel (VMT), vehicle hours of travel, and person hours of travel in the corridor. The analysis suggests that mobility needs can best be served by using excess HOV lane capacity as an HOT lane facility. Capacity expansion alternatives are also analyzed, including adding mixed-flow travel lanes or converting existing lanes to HOV or HOT lanes. Alternative toll levels are also simulated. Results show that managing capacity as an HOT or HOV lane could provide superior mobility benefits with a net decrease in VMT if capacity must be expanded.

Public concern over congestion on the nation's highways has increased in recent years. For example, in the Washington, D.C., area, daily person-hours of delay increased 114 percent between 1982 and 1993 (*1*). In the San Francisco Bay area, over 25 percent of freeway miles are congested during peak periods. This figure is expected to double in the next 12 years (*2*). Because of this increasing congestion, government officials have been under increasing pressure to "solve" the congestion problem. The traditional answer to "fixing" congestion—adding capacity—is increasingly seen as ineffective and has also been viewed as contributing to increased environmental problems.

Such concerns have encouraged efforts to manage new and existing road capacity in ways that decrease environmental impacts. Rather than expand highway capacity with traditional mixed-flow lanes, many regions have added high-occupancy vehicle (HOV) lanes with the goal of reducing congestion and improving air quality by increasing vehicle occupancy rates.

HOV lanes in the United States evolved from dedicated rapid transit bus lanes (*3*). In many places, these bus lanes had excess capacity and were opened to vans and carpools as a way of encouraging more efficient use of the road network. For example, the Shirley Highway in the Washington, D.C., area opened a reversible exclusive busway in 1969. In 1975 it was opened to vehicles with four or more passengers. The passenger requirement was subsequently lowered to three in 1989. One of the most successful HOV facilities in the country, these lanes currently carry more than half the peak-period commuters in the corridor, with an average travel time less than half that of the mixed flow lanes (*4*).

The Lincoln Tunnel contraflow bus lane is another example of a well-utilized HOV lane. One of the few facilities in the country of which buses are the main users, the contraflow lane carries nearly half of all bus riders entering the Manhattan central business district (CBD). The 2.5-mi (4.0-km) facility, which opened in 1970, decreased bus commute times, leading to increased ridership (*3, 5*).

However, not all HOV lanes have been as effective as those on the Shirley Highway and in the Lincoln Tunnel. This is partly due to the reduction in carpooling over the past 30 years. For example, in 1970 nearly 20 percent of commuters carpooled; by 1990, the number had dropped to 13 percent (*6, 7*). As carpool rates have decreased, there has been an increase in opposition to HOV lanes from drive-alone commuters who believe the lanes to be underutilized (though they may carry as many people as neighboring lanes). This has led to political pressure to convert these lanes to mixed-flow travel lanes.

An example of this phenomenon recently occurred in New Jersey, where the state removed HOV lanes on I-287 and I-80. The action responded to public pressure and to New Jersey Department of Transportation studies showing that the lanes were ineffective in reducing congestion or improving air quality (*8*). Interestingly, a special act of Congress was required to waive repayment of the $240 million in federal funding used for the HOV construction because those funds had been specially earmarked for HOV lane construction (*9, 10*).

An alternate approach that may more efficiently use HOV lane capacity and decrease political opposition is to charge single-occupant vehicles (SOV) that wish to use the lane. Fielding and Klein proposed high occupancy toll (HOT) lanes that maintain existing incentives for carpooling by allowing HOVs to use the lanes for free (*7*). However, to ensure that all capacity is used efficiently, SOVs can "buy into" the lanes.

In recent years, several projects have tested the HOT lane concept. State Route 91 in Southern California charges a variable toll for SOVs. Initially, HOVs were allowed to use the lanes for free and now are charged a discounted toll (*6, 11*). In San Diego, underutilized HOV lanes on I-15 were converted to congestion-tolled HOT lanes. Toll revenues are dedicated to improving transit and carpooling in the corridor. In Houston, Texas, the Katy Freeway has allowed HOV-2s to pay a fixed toll to use an HOV-3+ facility (*12*). These examples highlight the two situations in which understanding the differences between mixed-flow, HOV, and HOT lanes is most critical—when managing new or existing

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capacity on a congested roadway and managing an underutilized HOV lane.

The purpose of this analysis is to examine the travel impacts of converting HOV lanes to mixed-flow lanes versus HOT lanes. Alternative capacity-expansion regimes are also examined, such as adding new lanes versus converting existing lanes to HOV or HOT lanes. To compare differences between management regimes, a nested logit model that includes a departure-time choice nest was constructed that simulates the actions of a synthetic sample of commuters within a hypothetical highway corridor. The model is meant to show the relative differences among different policy options and is not meant to predict actual flow conditions in any particular locale.

Results strongly support the hypothesis that HOT lanes can better serve the mobility needs of the traveling public with less impact on the environment than mixed-flow lanes. In addition, other road-capacity management scenarios show that adding a mixed-flow lane is not the most effective means of increasing mobility and tends to substantially increase vehicle miles of travel (VMT).

SIMULATION MODEL

A modeling methodology originally developed by Chu was used for the analysis (*13*). Chu estimated a nested logit model of mode and departure-time choice and applied this within a simulated corridor. This was extended by analyzing two alternative routes (or lanes) that may or may not be mode dependent. These are the mixed-flow lanes versus a lane designated as either an HOV lane (restricted to HOVs) or an HOT lane (allowing both tolled SOVs and free HOVs).

Coefficients were not estimated for the model but rather borrowed from other studies. Rossi and Outwater discussed some of the problems with transferring mode choice parameter estimates (*14*). Although this may not be appropriate for analysis of specific projects, the purpose is general policy analysis of relative effects to compare alternatives. In addition, the inclusion of a departure-time choice model is not normally included, even in the most detailed travel-demand studies. Thus, although some accuracy was sacrificed by using borrowed coefficients, richness was added to the analysis by the inclusion of a detailed departure-time choice step within the model.

The model was calibrated to a base-case HOV scenario that provided realistic splits between modes and choice of lanes. The various components of both the demand side and supply side of the model are discussed below. This is followed by a description of the simulation and the iterative approach used.

Demand-Side Model

The demand model used in this simulation was a nested logit model based on work by Small (*15*), Chu (*13*), Chu and Fielding (*16*), and Noland (*17*). Figure 1 details the structure of the nested logit model. The bottom nest is the time-of-day choice. This was split into 1-min intervals relative to the desired "work start" time. Intervals up to 40 min early and 20 min late were used in the simulation. The second level of the nest is the choice of which lane to use (i.e., express/toll/HOV lane versus the nonexpress/mixed-flow travel lanes). The top level of the nest represents the choice of mode, in this case restricted to just HOV versus SOV.

Coefficients were not estimated for the model but from other studies. A sample enumeration (*18*) was then used to determine the choice probabilities with a synthetic sample of individuals.

The overall model structure can be defined as

$$\mathrm{P_n}(mlt) = \mathrm{P_n}(m|lt)\mathrm{P_n}(l|t)\mathrm{P_n}(t)$$

where $\mathrm{P_n}(mlt)$ represents the probability of choosing mode m given choice of lane l given departure time choice t. The nested logit structure defines a logsum (LS) term that is the logarithm of the sum of the utility of a given nest. This is defined as

$$\mathrm{LS} = \ln \sum_{i=1}^{k} \exp(U_i)$$

where U_i is the utility for the given nest summed over all the k choices within the nest. The choice probability is defined as

$$P(j|i) = \frac{e^{(U_i+\beta\mathrm{LS})}}{\sum_k e^{(U_i+\beta\mathrm{LS})}}$$

where

LS = logsum of lower nest,
β = coefficient of logsum, and
U_i = utility function of lower nest.

The following sections discuss the three model structures used within the nested logit model, including how the coefficients and logsums were selected. Table 1 summarizes all coefficients and logsums used in the analysis.

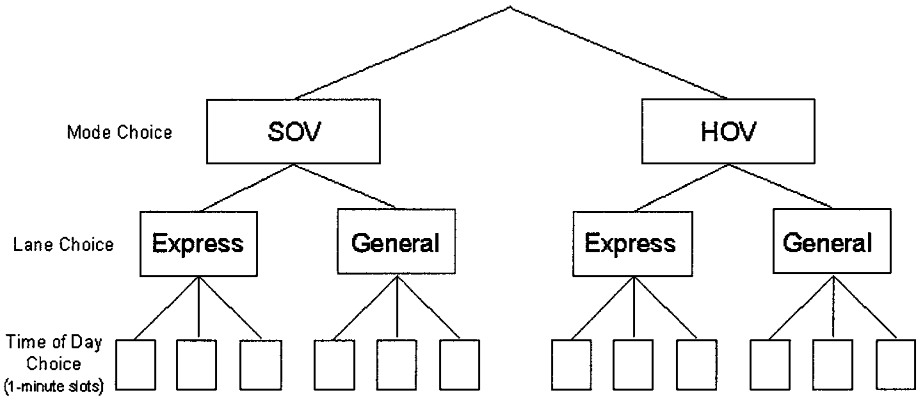

FIGURE 1 Representation of nested logit model (SOV express lanes not available during HOV or free scenarios; HOV express lanes not available during free scenarios).

TABLE 1 Nested Logit Model Coefficients

Model Type	Submodel	Variable	Symbol	Value	Source
Demand	*Mode Choice*	Logsum for SOV	ω_m = SOV	0.6842	Chu (*13*)
		Logsum for HOV	ω_m = HOV	0.2242	Chu (*13*)
		HOV Delay Coefficient	θ	-2.04	Dahlgren (*3*)
		HOV Constant	C_m	-2	Calibrated Value
	Lane Choice	Logsum for Express Lanes	ϕ_l = express	0.1	Calibrated Value
		Logsum for Mixed-Flow Lanes	ϕ_l = general	0.65	Parsons Brinckerhoff (*20*)
		Toll Coefficient	τ	-0.532	Chu & Fielding (*16*)
		Lane Constant	C_l	-1	Calibrated Value
	Time of Day	Travel Time Coefficient	α	-0.106 SOV -0.045 HOV	Small (*15*)
		SDE Coefficient	β	-0.065 SOV -0.054 HOV	Small (*15*)
		SDL Coefficient	χ	-0.254 SOV -0.362 HOV	Small (*15*)
		D_L Coefficient	δ	-0.58 SOV -1.14 HOV	Small (*15*)

Time-of-Day Choice

The method for determining when, during the morning peak, individuals will travel was based on previous work by Small (*15*). This work postulates that commuters want to minimize the costs of traveling to work while also arriving at work at some preferred arrival time. The costs include the travel time to work, those associated with arriving early or late, and a discrete penalty associated with arriving late. Based on this, Small estimated the following utility function (*15*):

$$U_t = \alpha T + \beta SDE + \chi SDL + \delta D_L$$

where

T = vehicle travel time,
SDE = schedule-delay early,
SDL = schedule-delay late, and
D_L = penalty term equal to 1 if individual arrives later than desired.

Schedule-delay early and late represent the difference between the actual work-arrival time (T_a) and the preferred arrival time (T_p). In the simulation, the variable used for work time was the time the traveler exits the highway corridor. The formulas are defined as follows:

$$SDE = \begin{cases} T_p - T_a, \ if > 0 \\ 0, \ \text{otherwise} \end{cases}$$

$$SDL = \begin{cases} T_a - T_p, \ if > 0 \\ 0, \ \text{otherwise} \end{cases}$$

Coefficients for this model were estimated by Small from a disaggregate logit model using data collected in the bay area (*15*). Small estimated general and mode-specific models. The differences in coefficients show that arriving late to work has higher costs for a carpool and that arriving early has lower costs relative to those traveling alone. Time spent traveling is both less onerous than for SOVs and less costly than the schedule-delay variables. The coefficient estimated in Small's (*15*) model are displayed in Table 1 and in the equations below as utility functions, specific to either the SOV or the HOV mode:

$$U_{t,SOV} = -0.106T - 0.065SDE - 0.254SDL - 0.58D_L$$

$$U_{t,HOV} = -0.045T - 0.054SDE - 0.362SDL - 1.14D_L$$

These coefficients were used to determine scheduling choice in the time-of-day nest of the model.

Lane Choice

The second nest of the model is the choice of route (or lane). For scenarios that involve an HOV or an HOT lane, some portion of drivers face a choice between mixed-flow and express lanes. It was assumed that HOV-2 vehicles would always be able to use the lane at no cost, although SOV vehicles could buy into the express lane in HOT-lane scenarios. The analysis used a flat toll rather than a congestion or variable toll. The base-case toll was set at 20 cents/mi (12.4 cents/km), which is comparable with an approximate average per mile toll rate on the CA-91 and I-15 HOT lanes (*11*, *19*). From that base, toll levels were also varied to test price sensitivity.

Chu and Fielding estimated a coefficient for the toll charge of −0.532, using stated preference data from the CA-91 corridor (*16*). Determining the logsum coefficients (based on the time-of-day nest) for express lanes proved more difficult. Few studies at this point have reported logsum coefficients. Parsons Brinckerhoff, in their study of the CA-101 corridor in Sonoma County, California, estimated a logsum coefficient of 0.65 at the level between toll and nontoll lanes (*20*). Based on this, a value of 0.65 was chosen for the mixed-flow lane and 0.1 for the express lane inclusive value term. Calibration of the model resulted in an alternative specific toll constant of −1.

This resulted in the following utility function for the choice of lane:

$$U_l = C_l + \tau T_l + \phi_l LS_{t,l}$$

$$U_{l,\text{mixed}} = -0.532T_l + 0.65_l LS_{t,l}$$

$$U_{l,\text{express}} = -1 - 0.532T_l + 0.1_l LS_{t,l}$$

where

C_l = alternative specific constant for choice of lane calibrated to −1 for HOT lanes,
T_l = toll,

τ = coefficient for T_l,
ϕ_l = logsum coefficient, and
$LS_{t,l}$ = logsum from time-of-day choice.

In simulations without an HOT or HOV lane, this nest was not included.

Mode Choice

Individuals face the choice of driving alone (SOV) or with others (HOV). For this analysis, HOV was restricted to two people in the vehicle. This is consistent with practices in most regions of the country. Some exceptions exist, such as the San Francisco Bay area, where only three-person carpools can use HOV lanes (*3*).

From Chu (*13*), an HOV delay penalty, which represents the time spent creating the carpool each morning, was also incorporated at this level of the model. Chu's work showed that delay factors, such as transit wait and transfer time, are best incorporated in the nests of the logit model rather than in the supply model (*13*).

Values for this delay factor vary. For example, in a study of CA-101 in Sonoma County, delay values of 5 min for HOV-2 and 7 min for HOV-3+ were used (*20*). Based on this, a value of 5 min was used. Dahlgren noted that studies show commuters value delays associated with carpooling at 40 times that of in-vehicle travel time (*3*). In the model, this implied a coefficient of −2.04 on the delay associated with the HOV mode. For actual travel times in the corridor, Small's coefficient (*15*) was used in the tradeoff between schedule delay and travel time, which for the HOV mode is actually less onerous than for SOV travel.

Chu estimated the logsum coefficients in his model from a 1972 sample of 991 commuters in the San Francisco Bay area for the Urban Travel Demand Forecasting Project (*13*). Based on this, Chu's inclusive value term for SOV of 0.6842 and for HOV of 0.2242 was used. The model was then calibrated to mode splits similar to those seen in average HOV lanes (*3*). *Average* in this case was defined as approximately 25 percent of vehicles being carpools. Calibration was achieved by varying the alternative specific constant for the HOV mode. A value of −2 gave "realistic" results.

The upper nest of the model, then, has the following utility function:

$$U_m = C_m + \theta D_m + \omega_m LS_{l,m}$$

$$U_{m,SOV} = -2.04 D_m + 0.6842\, LS_{l,m}$$

$$U_{m,HOV} = -2 - 2.04 D_m + 0.2242\, LS_{l,m}$$

where

C_m = alternative specific constant,
D_m = delay associated with HOVs,
θ = coefficient for D_m,
ω_m = alternative specific logsum coefficient, and
$LS_{l,m}$ = logsum from lane-choice nest.

Supply-Side Model

To calculate the level of congestion along the alternative lanes, the model used in this simulation was the one reported by the Bureau of Public Roads (BPR) (*21*). The formula is as follows:

$$T = l\left[T^0 + T^1\left(\frac{V}{C}\right)^{\epsilon}\right] = 5\left[1 + 0.15\left(\frac{V}{C}\right)^4\right]$$

where

T = travel time,
l = length of the facility,
T^0 = free-flow speed measure,
T^1 = constant,
V/C = number of vehicles leaving highway per time interval divided by capacity, and
ϵ = an elasticity parameter.

The parameters used in this model assumed a 5-mi (8-km) segment with a free-flow speed of 60 mph.

Simulation Methods

The model used an iterative algorithm to combine the supply and demand models and simulate a hypothetical segment of highway corridor. The corridor length was assumed to be 5 mi (8 km) long. As a comparison, the CA-91 and I-15 HOT lanes are 15 and 8 mi (24.1 and 12.9 km), respectively. The 5-mi (8-km) length was chosen for two reasons: first, because Chu estimated coefficients using a 5-mi (8-km) corridor; second, because using a shorter length provides the most conservative estimates of the benefits of HOV and HOT lanes. This occurs because commuters faced with longer, more congested corridors are more likely to carpool and pay to use a toll lane. In other words, the time savings accorded to carpoolers and toll-lane users increase with the length of the corridor. By using a 5-mi (8-km) corridor length, the policy analysis is applicable to all situations of at least that length.

Travelers consisted of a synthetic sample of 5,000 individuals who vary only over their desired work start time and an incremental travel distance once they leave the corridor. In reality, the work start time represented the time at which individuals leave the highway segment. The synthetic sample was normally distributed with a desired work start time of 8 a.m. and a standard deviation of 60 min. The additional travel time had a mean of 20 min and a standard deviation of 5 min.

The simulation used 5,000 individuals within the corridor as a balance between "realistic" conditions and computational efficiency. The capacities of the lanes were assumed to be 300 vehicles per hour (50 vehicles per 10-min time slot). Again, this capacity was chosen to match the number of individuals simulated as traveling in the corridor. If more realistic capacity levels of, for example, 2,100 vehicles per hour were used, then the synthetic sample would need to increase to 35,000 individuals, significantly lengthening the computational time required for the simulations to achieve convergence.

Using sample enumeration, the demand model then predicted the probability that a given individual would travel in a specific time slot (*18*). The time-of-day choice was based on 61 of the 1-min choices, varying from up to 40 min arrival time before the desired travel time and extending to 20 min after the desired arrival time. These were aggregated to travel time periods of 10 min in length to calculate travel times using the supply-side (BPR) formula. These travel times were used to calculate new choice probabilities until the simulation converged. Convergence was determined when the travel volumes between different iterations did not change significantly.

The analysis did not include many other factors that may influence the choice to use an HOV or an HOT lane. For example, Li estimated data collected on the CA-91 HOT lanes and found that various demographic factors are important in explaining the choice of whether to use a HOT lane (*22*). In contrast and similar to the analysis, Dahlgren based her analysis of HOV versus general-purpose lanes primarily on the travel-time differentials (*23*). Dahlgren, however, did not control for departure-time choice.

SIMULATION RESULTS

Conversion of Existing HOV Lanes

The current debate over the usefulness of HOV lanes has led to policy discussions about whether they should be removed or converted to HOT lanes. When HOV lanes have excess capacity (even if they are carrying commuters more efficiently than mixed-flow lanes), there is potential for political backlash against them. Official reaction to the public's discontent with underutilized HOV lanes can lead to their decommissioning, as was done on I-80 and I-287 in New Jersey, or the conversion of those lanes to an HOT lane, as was done in San Diego.

Simulations were run to analyze the effects of the two alternative conversion strategies on vehicle travel times, person travel times, and VMT in the corridor. Base-case results, for a highway corridor with one HOV lane and two free lanes, are shown in Table 2. As can be seen in the base case, 27 percent of the vehicles were HOV, of which about half used the HOV lane. The total number of vehicles was 3,929, with a total VMT of 19,644. Vehicle hours of travel (VHT) were 35,925, and person hours of travel (PHT) were 44,297.

Conversion of the HOV lane to a mixed-flow lane resulted in a significant increase in total vehicles, to 4,363, an increase of 11 percent. VMT increased to 21,814, whereas VHT and PHT dropped somewhat. Obviously, from an environmental perspective, the increased VMT from converting to all mixed flow lanes is not the best solution.

Conversion to an HOT lane, with a flat toll of $1 per vehicle, did not increase VMT as much as did conversion to the mixed-flow lanes (5.5 percent increase versus 11 percent increase). In this scenario, 24 percent of the vehicles in the corridor used the HOT lane, nearly double the use when the lane was restricted to HOVs. More importantly, both VHT and PHT decreased in this scenario relative to both the HOV base case and the mixed-flow lane alternative. The HOT lane alternative thus provided the greatest increase in mobility for travelers.

Accepting the assumptions of the model, these results clearly show the benefits of an HOT lane conversion strategy relative to converting HOV lanes to mixed-flow lanes. In all cases, HOT lanes decreased total VHT and PHT, either reducing VMT or not increasing VMT as much as the mixed-flow lane option. These results were replicated when different road capacities were input into the model.

The simulations did not fully capture all impacts from a change in the relative capacity within the corridor. In particular, new trips that were previously not taken due to high levels of congestion were not modeled. Other long-run-induced travel impacts, such as land-use changes, were also not included [for a full discussion of these issues see Noland (*24*)]. The lack of a full accounting of induced-travel impacts implies that the travel-time savings shown by these simulations are not correct. One would not expect any of these strategies to actually reduce congestion due to induced-travel effects. However, the simulated reductions in travel time are a good proxy for measuring mobility increases, that is, the level of new (or longer) trips that can now be made due to the increase in capacity. Thus, the discussion of relative benefits focuses on mobility benefits of the travel-time reductions rather than on congestion-reduction benefits (which are elusive).

Managing Road Capacity to Increase Mobility

As roads become more congested, public and political pressure to expand road capacity builds. However, the larger questions are these: How can existing lane mileage be better managed? How can new capacity be added to increase mobility with the least impact on mileage, hours traveled, and the environment? Although there are many strategies to better manage highway capacity, this paper focuses on two policies—"taking a lane" for either an HOV or HOT lane and adding a lane of new capacity.

Simulations of various alternative strategies were run and results are shown in Table 3. A baseline of three mixed-flow lanes was used for comparison. Converting a mixed-flow lane to an HOV lane resulted in about a 10 percent decrease in VMT. Conversion to an HOT lane resulted in a 5 percent decrease in VMT. Mobility, as measured by VHT and PHT, would decrease slightly if the taken lane were converted to an HOV lane and increase marginally if it were an HOT lane.

Under either conversion scenario, the model predicted that a substantial number of commuters would opt to carpool to avoid substantial delay in the mixed-flow lanes. Specifically, in the base case, 25 percent of commuters carpool. In the HOV scenario, that number increased to 43 percent and, in the HOT lane, to 34 percent. Although this difference represents a substantial increase in carpooling, it is not unreasonable when compared with successful HOV lanes, for example, Shirley Highway (*4*). However, such results require that the corridor be located in an area where a substantial number of travelers have similar origin-destination patterns, that is, a region with a high percentage of employment in a CBD.

Pursuing the second strategy of increasing road capacity also highlights the importance of management strategies. Adding a mixed-flow, an HOV, or an HOT lane provided relatively similar levels of increased mobility (increases of 22 to 26 percent). However, adding a mixed-flow lane increased the VMT in the corridor and provided a lower level of increased mobility, compared with adding an HOT lane

TABLE 2 Comparison of HOV, Mixed-Flow, and HOT Lane Scenarios

	Single Occupant Vehicles (SOV)		High Occupant Vehicles (HOV)		Summary Data			
Scenario	**General** (% of Vehicles)	**Express** (% of Vehicles)	**General** (% of Vehicles)	**Express** (% of Vehicles)	**Total Vehicles**	**VMT**	**VHT**	**PHT**
HOV	73	0	14	13	3,929	19,644	35,925	44,297
Mixed Flow	85	0	15	0	4,363	21,814	35,343	40,636
HOT	65	15	11	9	4,146	20,732	33,201	39,694

NOTE: Compares three-lane highway segment; in HOV and HOT scenarios, one lane is devoted to an express lane. 1 mi = 1.6 km.

TABLE 3 Comparison of Highway Management Strategies

	Vehicles	VMT	VHT	PHT	No. of People SOV	No. of People HOV
Baseline: Three Mixed-Flow Lanes	4,363	21,814	35,343	40,636	3,726	1,274
Take a Lane for HOV Lane	3,929	19,644	35,925	44,297	2,858	2,142
Take a Lane for HOT Lane	4,146	20,732	33,201	39,694	3,293	1,707
Add Mixed-Flow Lane	4,448	22,238	27,670	31,110	3,896	1,104
Add HOV Lane	4,126	20,628	27,143	32,380	3,251	1,748
Add HOT Lane	4,265	21,326	26,013	30,371	3,530	1,469

NOTE: Add lane scenarios, add one lane or 300 vehicles per hour of capacity. 1 mi = 1.6 km.

or an HOV lane. This occurred because adding a mixed-flow lane provided no incentive for commuters to carpool, and therefore there were more vehicles in the corridor.

The reductions in VMT come from the increase in the number of commuters that opt to carpool. However, because the HOT lane allows more efficient use of the express lane capacity (because SOV drivers can buy in), there was only a 15 percent increase in the number of HOV commuters. This compares with a 37 percent increase if the lane were managed as an HOV lane. This difference may imply that adding an HOT lane could be particularly effective in areas with scattered origin-destination patterns, where commuters find it difficult to carpool.

This analysis shows that if planners and highway officials want to improve mobility, serious consideration should be given to taking a lane for an HOT lane or adding an HOV or HOT lane as alternatives to new lane construction. These alternative measures all provide mobility benefits (which would allow more people to travel) without an increase in VMT (relative to the baseline case of three mixed flow lanes).

Effect of Corridor Length

As mentioned earlier, the base-case corridor length was 5 mi (8 km). Although this length provided conservative estimates of the benefits of HOV and HOT lanes, it is important to understand how commuter behavior may change with increased corridor length. Simulations of a three-lane highway segment, with two mixed-flow lanes and one HOT lane, were done for corridor lengths of 5, 10, and 15 mi (8, 16, and 24 km). The results show that longer corridors offer commuters larger benefits for carpooling. In other words, the travel-time savings available to those who carpool began to outweigh the coordination costs of carpooling. For example, in a 5-mi (8-km) corridor, 21 percent of vehicles were HOV; in a 15-mi (24-km) corridor that proportion increased to 43 percent. This effect means that there were 16 percent fewer vehicles in the corridor for a 15-mi (24-km) segment than for a 5-mi (8-km) segment. Table 4 shows the results for this analysis.

Effect of Toll Level

Varying the HOT lane flat toll had the largest effect on the portion of SOV commuters who opted to use the toll lane. As the toll increased, commuters who had formerly chosen to pay the toll now opted to use the mixed-flow lanes (Table 5). Total VMT decreased as the toll increased from $0.50 to $2.50, because a small fraction of SOV commuters switched to carpooling. Regardless of the toll level, the mobility (VHT) benefits were greater for an HOT-lane strategy than for converting an HOV lane to a mixed-flow lane.

CONCLUSIONS

This analysis highlights two key findings. First, construction of new mixed-flow lanes or conversion of existing HOV lanes can lead to increases in VMT that are likely to have negative environmental impacts. This result occurs due to modal shifts and rescheduling effects without consideration of possible inducement of new trips. Second, mixed-flow lanes may not provide the greatest mobility benefits. Instead, HOT lanes offer the possibility of larger reductions in VHT and PHT time because they preserve incentives for higher vehicle occupancy and allow more efficient use of lane capacity.

These findings are particularly relevant because of the current debate over the usefulness of HOV lanes. When HOV lanes have excess capacity (even if they are carrying commuters more efficiently than mixed-flow lanes), there is potential for political pressure to remove the lanes. Official reaction to the public's discontent with underutilized HOV lanes can lead to the decommissioning of HOV lanes, as was done on I-80 and I-287 in New Jersey, or the conversion of those lanes to HOT lanes, as was done in San Diego.

TABLE 4 Effect of Corridor Length on HOT Lane Usage

	Distribution of Vehicles between Lanes		Distribution of Vehicles between Mode		Summary Data			
Corridor Length (mi)	**Mixed Flow** (% of Vehicles)	**Express** (% of Vehicles)	**SOV** (% of Vehicles)	**HOV** (% of Vehicles)	**Total Vehicles**	**VMT**	**VHT**	**PHT**
5 (Base Case)	76%	24%	79%	21%	4,146	20,732	33,201	39,694
10	75%	25%	68%	32%	3,792	37,917	51,861	67,958
15	73%	27%	57%	43%	3,489	52,331	65,143	93,036

NOTE: Compares highway segment with two mixed-flow lanes and one HOT lane with an SOV toll of $0.20/mi. 1 mi = 1.6 km.

TABLE 5 Effect of Toll on Mileage and Travel Time

Toll ($)	Vehicles	VMT	VHT	PHT
0.50	4,177	20,887	33,165	39,465
1.00	4,146	20,732	33,201	39,694
1.50	4,118	20,590	33,326	40,011
2.00	4,092	20,462	33,510	40,379
2.50	4,070	20,348	33,725	40,771

NOTE: Assumes one express lane and two mixed-flow lanes with total capacity of 900 vehicles/h. 1 mi = 1.6 km.

This research effectively suggests that transportation planners should strongly consider HOT lanes as an alternative to full decommissioning of HOV lanes.

In addition, the research shows that HOT lanes provide an effective management alternative in congested corridors where a lane could be converted or an additional lane built. Although this research did not consider the costs of the various alternatives, it seems likely that conversion of existing lanes to HOV or HOT lanes should have much lower capital costs than construction of a new lane.

Additional research should be undertaken to refine the model and to incorporate other scenarios. In particular, it would be helpful to use data from a passenger survey to reestimate the model rather than to use coefficients from other studies. Incorporating parallel routes into the model would also give a fuller understanding of how commuters react to a variety of highway management alternatives. Linking this model to the Environmental Protection Agency's (EPA) mobile-emissions model would also provide more insights into the environmental impacts of different alternatives. Finally, it would be interesting to investigate the impact of HOT lanes with congestion-based tolls. The flat toll rate used in the simulations showed HOT lanes to be superior under various tolling levels, but a congestion-based toll may provide even more benefits. Additional analysis could also attempt to recycle tolling revenue into transit options and include transit in the mode-choice model.

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