

Is Traffic a Problem that is Beyond Us?

Are we stuck with traffic for good? There doesn't seem to be enough money anywhere to build more roads or to build and operate attractive transit alternatives. Even if money was available, transportation projects take years to complete. New roads seem to be congested from the day they open. In the meantime, traffic just gets worse and worse.

Is this a history we are condemned to repeat? Frustrated commuters on the Sunol Grade – the Bay Area's most congested corridor – want to know. A new lane is being added. Will the new lane be one more example of too little too late, obsolete as soon as it opens? It very well could be.

Caltrans will add a two-person carpool lane that will be congested virtually the day it opens. The Sunol Grade already carries enough two-person carpools to fill the new lane. Congestion in a carpool lane eats into time savings, destroys the incentive to carpool and leads to even greater congestion in the other lanes.

The new lane on the Sunol Grade can be an opportunity to break out of the vicious cycle where new roads fill up as quickly as they are built. An innovative approach to make our roads work harder and smarter is to build the new lane as a barrier-separated, reversible Express Lane. This way, all available road space is used most efficiently and moves more cars and people. An Express Lane also insures that travelers will always have a choice – to take a fast trip when they really need it.



Congestion on Sunol Grade. Photo: Valley Times.

This report is part of the Environmental Defense Fund's "Escape from Gridlock" series that explores state-of-the-art transportation solutions in the Bay Area.

In this report:

EDF demonstrates that Caltrans' plan for a two-person carpool lane on the Sunol Grade will be obsolete the day it opens. We can unlock gridlock on the Sunol Grade, however, if the new lane is operated as an Express Lane that gives priority to three-person carpools and allows other cars to access the lane for a fee.

This is EDF's second report on the Sunol Grade. The first report, *Stop Stalling on Sunol*, presented better transportation choices with Express Lanes and movable barriers to save time and money on the Sunol Grade.

The Current Sunol Grade Plan: Obsolete from Day One?

It's a cramped and slow slog to work on the Sunol Grade. The three southbound lanes are "full" at rush hour and have been for several years. An explosion of corporate offices, jobs, and long-distance commutes has made the Sunol Grade a central artery of the Bay Area.

When the Sunol Grade is widened, planners expect to see the release of enormous "pent-up demand" for more travel across the Sunol Grade. Motorists will hop on because – finally – they can.

We have all seen new roads fill up with traffic. Caltrans' plan for congestion relief will be quickly undone by the release of pent-up demand, and because there are already enough two-person carpools to fill the planned two-person carpool lane. EDF's analysis shows that despite the addition of a lane to the Sunol Grade, congestion will reoccur with as little as a 10% increase in travel demand. Most importantly, congestion will occur in the new carpool lane as well as in the other three southbound lanes. Simply put, new capacity on the Sunol Grade will induce new traffic, and congestion will be reestablished. To this must be added "normal" growth expected in the corridor.

Growth in Travel Demand on the Sunol Grade over Five Years	
Due to induced traffic	30%
Due to population and job growth – Metropolitan Transportation Commission forecast	12%
Total	42%

This vicious cycle of congestion, however, can be avoided. There are effective and proven alternatives to successfully unlock the gridlock on the Sunol Grade.

Solving the Traffic Problem: Roads That Work Harder and Smarter

An Express Lane on the Sunol Grade will have a bigger impact reducing traffic than the currently planned carpool lane. The key is to make sure the new lane operates at peak efficiency. Several steps will accomplish this. The first step provides unrestricted access to vehicles with three or more occupants and allows a limited number of two-person carpools and solo-drivers to access the lane for a fee. The second step uses the revenues to increase commuter choices with expanded Altamont Commuter Express train service and express buses. The third step increases the capacity of the new lane by separating it from congested traffic. A final step operates the new lane as a reversible lane that serves northbound traffic in the evening.

Step 1: Express Yourself

EDF's analysis finds that the number of three-or-more carpools on the Sunol Grade will not cause congestion in the new lane. If this were the only step taken, however, the carpool lane would not be fully utilized. There are not enough three-person carpools to make efficient use of the lane space.

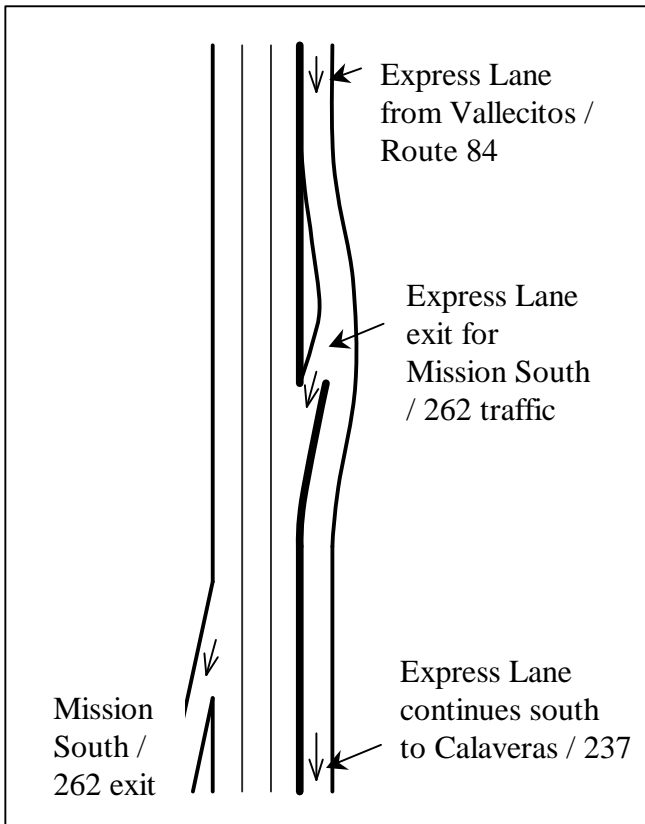
An Express Lane solves this problem by making this excess space available to two-person and solo-driver vehicles. Cars with fewer than three people that wish to use the Express Lane use "transponders" to pay a fee. Transponders are wallet-sized electronic devices that clip to the car's sun visor. Drivers are billed monthly only for the trips they take. The fee is adjusted by time of day – it would decrease during off-peak periods to encourage the most efficient use of the lane.

Step 2: More Choices

Revenues from the Express Lane can be used to fund alternatives such as expanded Altamont Commuter Express train service and express buses that use the new lane

Step 3: A Simple Separation

To increase capacity and to avoid interrupting the flow in the faster-moving Express Lane, the new lane should be separated from the other lanes. This can be done either by use of pylons, or by use of a fixed or movable barrier. In addition to maximizing throughput of the Express Lane,



separation also simplifies enforcement. Conditions on the Sunol Grade are quite favorable for separating the new lane from the other lanes – there are very few travelers to intermediate destinations, so multiple entry and exit points to the Express Lane are unneeded. An intermediate exit for traffic bound for the Mission South exit will suffice.

If You Could Increase Your Productivity by 50% You'd Do It, Right?

There is a simple key to a huge increase in the productivity of our roads: do not let congestion hinder smooth traffic flow. A congested lane – with stop-and-go conditions – is a lane operating far below its capability. By maintaining smooth traffic flow, an Express Lane moves far more people and cars.

A second boost in productivity occurs by separating the Express Lane from the other lanes. This eliminates interference from lane-change merges, further enhancing the ability of the new lane to move more people and cars.

Finally, a fixed or movable barrier allows the Express Lane to be reversed, providing a huge benefit in serving the evening commute.

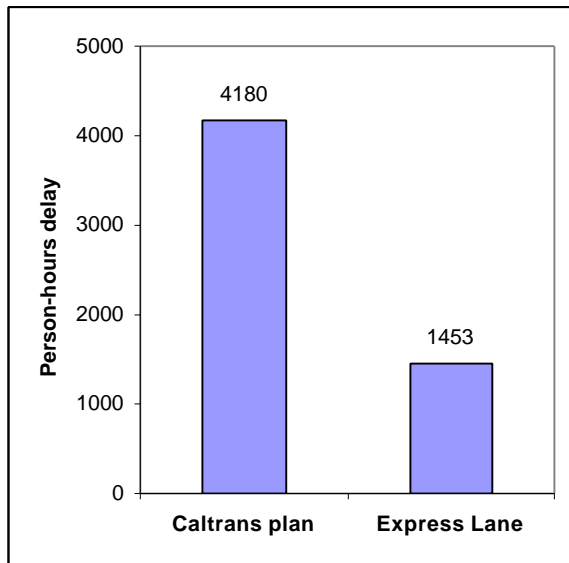
Step 4: Double the Bang for the Buck

This barrier-separated lane can be “borrowed” to serve northbound traffic in the evening. Traffic on the Sunol Grade is highly directional and projected to become even more so in the future. Commuters travel southbound in the morning and northbound in the evening. Thus, a single reversible lane that serves both of these commutes makes perfect sense. Moreover, funds are not yet available to provide users of the new southbound lane any relief on their homebound journey. Rather than waiting for an additional \$100 million to become available to complete the job, a barrier-separated lane can complete the job years sooner and at a fraction of the cost.

Traffic is Not a Problem Beyond Us

EDF's analysis shows that under Caltrans' current plan both the general purpose lanes and the new lane will be significantly congested. An Express Lane will be completely uncongested, and congestion in the general purpose lanes will be greatly reduced. In fact, Express Lanes will reduce total delays by two-thirds.

Express Lanes reduce total person hours of delay by two-thirds compared to Caltrans' plan



To solve congestion in an era of expanding transportation needs and limited resources we must seek innovative and efficient

approaches to the problem. Express Lanes are a proven solution that benefits users and non-users alike by increasing the number of people and cars that can use the lane. A free option exists for everyone while at the same time Express Lanes generate new funds for

	Current Caltrans Plan	Express Lanes
Features		
Unlimited, free access available to...	Two-or-more per car	Three-or-more per car
Limited access available to...	None	Two-or-more per car, solo drivers
Barriers	No separation	Yes
Serves evening commute?	No, not reversible	Yes
New lane throughput capability (vehicles per hour)	1700	2100

additional travel choices in the corridor. Express Lanes make best use of available space and provide Sunol Grade commuters with a quick trip to and from work. We have the technology and tools at hand to deliver a faster, smarter, cleaner commute on the Sunol Grade.

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*This report is available online at:
<http://www.edf.org/pubs/Reports/SunolGrade>*

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Appendix A. The speed-flow relationship on the Sunol Grade.

A congested lane is a lane that is operating well below capacity. In fact, roads function most poorly just when they are most needed. Traffic engineers know this as the “speed-flow” relationship.

Figure A-1 shows a theoretical speed-flow curve. When there are very few vehicles on the road – the upper left part of the curve – traffic has no problem moving along quickly. But as more vehicles join the traffic flow, additional crowding leads to slower speeds. As the number of vehicles approaches the capacity limit of the road – 2200 vehicles per hour per lane in this case – traffic slows down further. The curve shows that throughput at or near this maximum capacity can be achieved with speeds of 40 to 50 miles per hour.

The curve also shows, however, that at maximum capacity traffic flow is in danger of “breaking down.” With no increase in traffic – the near vertical section of the curve at its rightmost point – speeds can suddenly decline, leading to a loss of throughput. The lower section of the curve represents the “traffic flow breakdown” region, where stop-and-go traffic conditions lead to low vehicle throughput *and* slow speeds.

Figure A-2 shows observed speeds and traffic flows on the Sunol Grade.¹ Each point represents a particular location and 15-minute time period during which traffic counts were conducted. While the observed data do not line up precisely with the theoretical curve, the data do show the general relationship, including a number of observations of speeds below 15 miles per hour, with the consequent loss of throughput.

Figure A-1
Theoretical Speed-flow Relationship

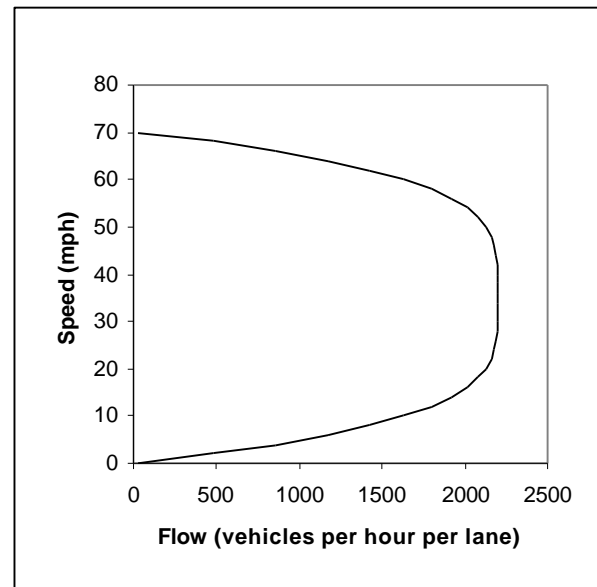
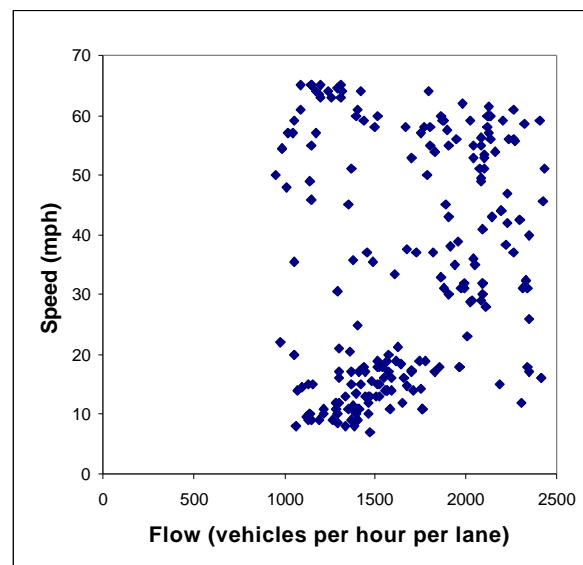


Figure A-2
Actual Speeds and Flows – Sunol Grade



¹ Source: *Technical Report on the I-680 Traffic Operations Study*, TJKM Transportation Consultants for Alameda County Congestion Management Agency, Contra Costa Transportation Authority, Santa Clara Valley Transportation Authority, December 1997, Table Ic, p. 10, and Table IVb, p. 15, for March 12, 1997.

The general speed-flow relationship is important to an appreciation of the benefits of an Express Lane: it keeps traffic flow out of the “breakdown region.” By maintaining smooth traffic flow, an Express Lane moves far more people and cars than a congested lane does.

Appendix B. Queuing and Speed-flow Model

The analyses in this report are conducted with a model that represents the traffic-carrying capability of the Sunol Grade. The model accounts for two important features of traffic flow on the Sunol Grade: excess demand causes the formation of queues; and such excess demand/queues affect the traffic-carrying capability of the road. The model’s key output is the vehicle hours of delay that occur for a given level of demand.

The queuing model was used with observed traffic volumes and delays to derive parameters and base case demands for the Sunol Grade. Table B-1 shows the calculations for existing conditions during the morning peak period. Measured travel times are used to calculate the delays for trips ending at the time shown.² Importantly, free flow conditions – a 20-minute travel time for the trip between Bernal Avenue in Pleasanton and Calaveras Boulevard / Route 237 in Milpitas, do not exist in the 5:30 to 9:30 period. The maximum measured travel time – one hour and eight minutes for a trip ending at 8:00 AM – represents a 48-minute delay.

Table B-1
Existing Conditions – Sunol Grade

Time	Through-put capability (veh/h)	Cumulative capability (veh)	Travel time (h:m)	Delay (h:m)	Time - queue (h:m)	Queue arrival rate (veh/h)	Cumulative arrivals (veh)	Vehicles in queue (veh)	Resulting capability (veh/h)	Person arrival rate (per/h)	Person-hours of delay (per-h)
5:00	6300	0	0:20	0:00	5:00	0	0				
5:30	6157	3078	0:21	0:01	5:29	6369	3181	102	6157	8015	32
6:00	5320	5738	0:25	0:05	5:55	6138	6438	700	5320	8209	168
6:30	4200	7838	0:40	0:20	6:10	8400	10358	2520	4200	9878	551
7:00	4200	9938	0:55	0:35	6:25	8400	12993	3055	4200	6639	1213
7:30	4200	12038	1:00	0:40	6:50	5040	15133	3095	4200	5393	1654
8:00	4200	14138	1:08	0:48	7:12	5727	16791	2653	4200	4178	1940
8:30	4200	16238	1:00	0:40	7:50	3316	18449	2211	4200	4179	1940
9:00	4200	18338	0:52	0:32	8:28	3316	20112	1774	4200	4190	1588
9:30	4434	20556	0:42	0:22	9:08	3326	21888	1333	4434	4476	1257
10:00	6300	23706	0:20	0:00	10:00	3635	23706	0	6300	4580	728
											11071

The model is based on a free-flow capability at the Mission Boulevard South bottleneck of 2100 vehicles per hour per lane.³ The capability of the road and the delay times are used to calculate the number of vehicles in the queue at each half-hourly interval, with one complication: the capability of the road is a function of how crowded the road is. Thus, there is a feedback from the

² Travel times from *Technical Report on the I-680 Traffic Operations Study*, Table IVa, p. 14, for March 12, 1997.

³ While figure A-2 indicates there are segments of the Sunol Grade that achieve throughputs of nearly 2500 vehicles per hour per lane, these segments are mostly downstream of the existing bottleneck.

size of the queue to the throughput capability of the road. An iterative procedure is used to find the equilibrium solution. The feedback relationship is linear between a zero-length queue and a queue length of 500 vehicles per lane: the maximum throughput capability occurs at a zero-length queue, a minimum capability of 1400 vehicles per hour per lane occurs when the queue meets or exceeds 500 vehicles per lane.

Table B-1 also shows how the average vehicle occupancy on the Sunol Grade – 1.26 persons/vehicle – is used to calculate the person arrival rate, and finally, the person hours of delay experienced each day during the 5:00 AM to 10:00 AM period. In the base case the total daily delay is 11071 person-hours.

Figure B-1 provides a graphical illustration of the queuing calculations for existing conditions on the Sunol Grade during the morning peak period. The lower line shows the capability of the road to move traffic. The slope of the line represents the capacity of the road – in vehicles per hour – at each time interval. The upper line shows the cumulative number of vehicles trying to use the road. The slope of the upper line represents the “arrival rate” of vehicles to the queue. The horizontal distance between the two lines represents the delay that a vehicle experiences in the queue – the time between arrival and departure. The vertical distance between the two lines represents the number of vehicles in the queue at each time.

Figure B-1
Queue Diagram – Existing Conditions

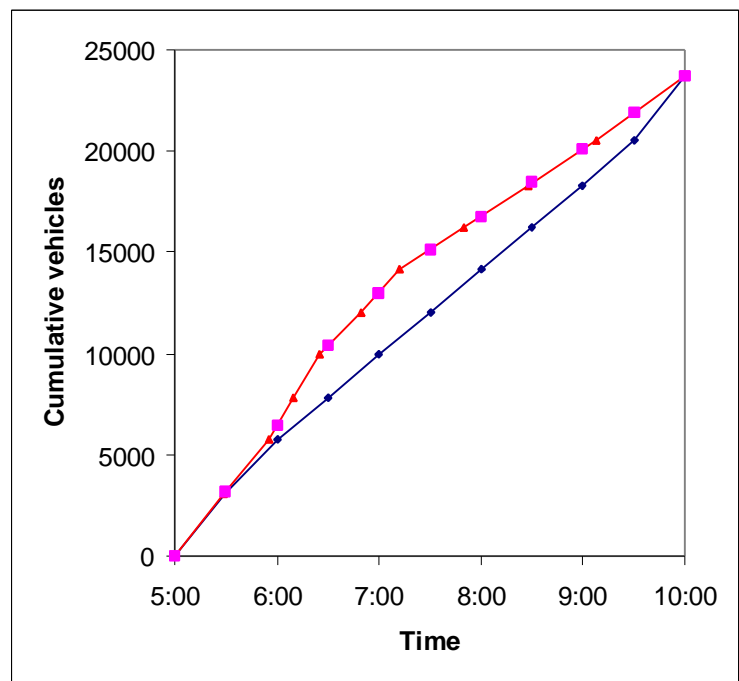


Figure B-1 shows that significant delays begin to occur on the Sunol Grade as early as 5:30 in the morning. The delay is greatest for trips ending at about 8:00 AM. The queue is not cleared until about 10:00 AM.

The model is a somewhat simplified representation of the Sunol Grade, since the corridor is represented as a single queue. Since the Sunol Grade has been observed, however, to have a main bottleneck at Mission Boulevard South,⁴ the queuing model accounts for the major feature of the Sunol Grade. Even changes that tend to move or redistribute this bottleneck will still leave this major feature – the formation of a queue or queues because of excess demand – intact.

⁴ Technical Report on the I-680 Traffic Operations Study, p. 8.

Appendix C. High Occupancy Mode Share Model

The analyses in this report include a model of the mode share of High Occupancy Vehicles (HOVs) on the Sunol Grade. The model is based on the work of Dahlgren.⁵ Dahlgren showed how a full-scale travel demand mode share model could be adapted to analysis of HOV lanes. While there are many factors that affect how many people will use a shared-ride mode in a corridor, only one factor is relevant to the addition of an HOV lane: the amount of travel time savings provided by the lane.

Dahlgren used a binomial logit mode choice model that allowed comparison of shared-ride modes with single-occupant modes. This analysis extends Dahlgren's method so that two-person HOVs can be distinguished from three-or-more-person HOVs. A multinomial logit mode choice model is used. There are three modes: drive alone; two-person shared ride, and three-or-more-person shared ride.

The model is calibrated to the existing mode shares on the Sunol Grade. This calibration is simplified because currently there is no HOV lane on the Sunol Grade. That is, the time savings available to shared ride modes are currently zero. The 1997 traffic operations analysis observed that 20% of the vehicles on the Sunol Grade were HOVs: 15% two-person HOVs, and 5% three-or-more-person HOVs.⁶ The average occupancy of three-or-more-person HOVs is 3.2 persons per vehicle. The model is based on the person mode share. The vehicle proportions translate to person mode shares of 23.8% for two-person HOVs, and 12.7% for three-or-more-person HOVs. That is, 23.8% of the people currently traveling on the Sunol Grade can be found in two-person HOVs, and 12.7% of the people can be found in three-or-more-person HOVs.

The effect of travel time savings in the HOV lane depends on the value of the travel time coefficient in the mode choice model. Dahlgren's review showed that this coefficient value has varied in different models. Dahlgren used a value of $-0.04/\text{minute}$ as representing the middle of the range, with sensitivities of $-0.02/\text{minute}$ and $-0.08/\text{minute}$. This analysis uses the $-0.04/\text{minute}$ coefficient value.

There are two different applications of the HOV mode share model. One application is for an HOV lane free to two-person vehicles, as well as to three-or-more-person vehicles. The second application is for an HOV lane that is free to only three-or-more-person vehicles. In the first application, both two-person and three-or-more-person vehicles benefit from the time savings of the HOV lane. Therefore, the proportion of people using each of these modes increases with increasing time savings. Figure C-1 shows how these mode shares depend on the time savings provided by the HOV lane.

In the second application, where only three-or-more-person vehicles can take advantage of the

⁵ "High Occupancy Vehicle Lanes: Not Always More Effective than General Purpose Lanes," Joy Dahlgren, *Transportation Research A*, Vol. 32, No. 2, pp. 99-114, 1998.

⁶ Letter dated March 10, 1998 from Gary Kruger, TJKM Transportation Consultants, to Jean Hart, Alameda County Congestion Management Agency.

Figure C-1
**Mode Shares vs. Time Savings–
 Two-or-more-person HOV Lane**

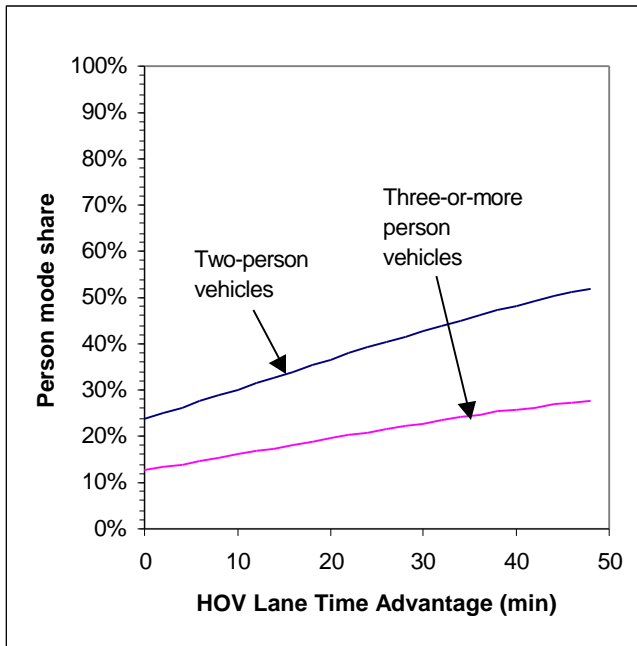
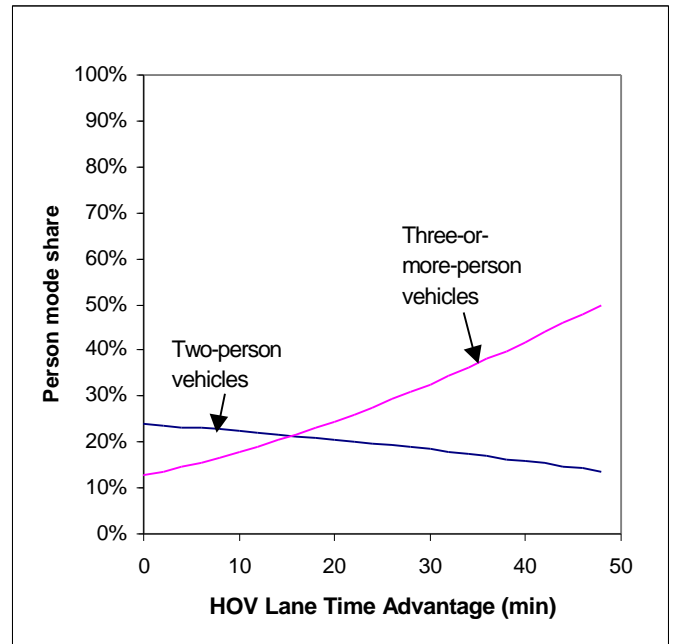


Figure C-2
**Mode Shares vs. Time Savings–
 Three-or-more-person HOV Lane**



time savings provided by the HOV lane, the mode share of three-or-more-person vehicles increases with increasing time savings, while the drive-alone and two-person mode shares decrease with increasing time savings. That is, when the three-or-more-person HOV lane provides a greater incentive for travelers to use this mode, more people switch to this mode. Figure C-2 shows how the two-person and three-or-more-person mode shares depend on the time savings provided by the HOV lane.

Appendix D. Demand Growth and Induced Demand on the Sunol Grade

Increases in demand for travel on the Sunol Grade are an important issue for a number of reasons. The lane addition to the Sunol Grade has been promoted on the basis of promised congestion relief. Traffic growth may quickly destroy that promise. In addition, the Sunol Grade is the most significant congested link in a corridor that is a major focus of sprawl development, spreading from the San Francisco Peninsula as far as the Central Valley. To the extent that capacity expansion on the Sunol Grade affects development in these areas, the capacity expansion has important environmental ramifications.

There are several potential sources of traffic increases on the Sunol Grade. The immediate effect will probably be caused by changes in route choice by travelers. Travelers who currently avoid the Sunol Grade because it is so congested will switch back to the Sunol Grade in response to improved travel times. Two longer-term effects also will lead to traffic growth on the Sunol Grade. First, population and job growth in the corridor will increase the number of people desiring to travel on the Sunol Grade. Second, the capacity addition itself may “induce” more

traffic. These two effects are discussed in this Appendix.

Sunol Grade Traffic Increases Due to Population and Job Growth

The Metropolitan Transportation Commission projects that the demand for travel (person trips) in the Sunol Grade corridor will more than double between 1990 and 2020, outpacing regional growth of 37% by a wide margin.⁷ While these are sobering projections, they actually represent a slower growth rate than has recently occurred in this corridor. Commuting on the Sunol Grade increased by 65% in just the 1990 to 1998 period.

The Metropolitan Transportation Commission projects that morning period person trips will grow to 110,100 by the year 2010 compared to 51,200 in 1990. Accounting for growth through 1998, the average growth rate between 1998 and 2010 is projected to be 2.2% per year. This is far lower than the 1990 to 1998 growth rate of 6.5% per year.

The 2.2% per year forecasted growth rate means that over five years person trips are expected to increase by 11.7%.

Sunol Grade Traffic Increases Due to Induced Traffic – Overview

The effects of road capacity expansions on travel and land use have been difficult to isolate because there are other factors – such as population growth and economic growth – which generally accompany road capacity expansion. Recent studies, however, account for multiple effects, and distinguish those due solely to road capacity expansion from other effects. These studies indicate that there is a substantial “induced demand” effect – a 10% increase in capacity, for example, induces a 6 to 9% increase in traffic within four years.

Such effects are consistent with economic theory. Capacity expansion reduces the “effective cost” of driving. The effective cost includes both monetary costs (e.g., gasoline) and non-monetary costs (chiefly time spent traveling). The reduction in effective cost of a good means that more of that good will be purchased.

A Transportation Research Board committee that examined the effects of induced demand on air quality concluded that the effects of induced demand were relatively small. The study indicated, however, that there were specific cases in which induced demand effects would be most significant.

Other recent studies in California and the United States as a whole have improved on the research that was available at the time the Transportation Research Board committee produced its report.

A British Department of Transport report also addresses the question of induced demand at length. This report strongly supports the conclusion that induced demand effects are significant.

Induced traffic as analyzed in these recent studies does not account for additional effects due to

⁷ *I-680 Corridor Major Investment Study, Technical Memorandum, Phase II, Task 2: Demographic Projections and Travel Implications*, Metropolitan Transportation Commission, July 15, 1999.

changes in land uses that may be induced by the Sunol Grade capacity expansion. This is because these results “controlled for” the effect of population increases. Population and land use changes induced by additional highway capacity are more difficult to take into account. Available research, however, indicates that these effects are also significant.

Induced Traffic – Recent Studies

Hansen and Huang used statistical techniques to examine 18 years of California county and metropolitan area data.⁸ The statistical techniques “control” for the effects of population growth and economic growth, as well as other factors, including general effects over time and area-specific differences, to isolate the independent influence of road capacity on travel. Since the “induced demand” effect is one that takes place over time, Hansen and Huang’s analysis allows for “lags” in the impact of capacity expansions.

Hansen and Huang find that, at the county level, the long-run elasticity of vehicle-miles traveled (VMT) with respect to state highway lane miles is 0.62, realized after a period of two years.⁹ At the metropolitan area level, the long-run elasticity is 0.94, realized after a period of four years.¹⁰ Hansen and Huang note that “[t]he higher lane-mile elasticities found in the metropolitan models suggest that adding lane-miles in a given county increases VMT throughout a wider region. This will occur if, for example, increasing the capacity of a highway in a given county induces commuting to or through that county from other counties in the region.” This is certainly the case with respect to the Sunol Grade, which essentially connects two counties (Contra Costa and Alameda) with a third (Santa Clara). Through-commutes from San Joaquin and Stanislaus Counties are also significant on the Sunol Grade. Thus, use of the metropolitan area result is indicated.

Hansen and Huang conclude, “the full impact of vehicle-miles traveled materializes within five year of the change in road supply.”¹¹ Since their analysis also takes account of general trends in travel in addition to changes in road capacity, as well as population, income, and gasoline prices, they note, “even when all these factors are accounted for, there has been a sharp increase in the propensity toward vehicle travel over the period of this study [1973-1990], particularly during the late 1980s.”¹² Nevertheless, the independent effect of road supply on vehicle-miles traveled is highly statistically significant.

Noland used a method similar to Hansen and Huang’s with data from each state over the 13-year period 1984 through 1996.¹³ As in Hansen and Huang’s analysis, the effects of population growth, economic growth (income per capita), and gasoline prices were controlled for. Noland used a “distributed lag” model to determine the long-run effects of road capacity additions on

⁸ “Road Supply and Traffic in California Urban Areas,” Mark Hansen and Yuanlin Huang, *Transportation Research A*, Vol. 31, No. 3, pp. 205-218, 1997.

⁹ *Ibid.*, p. 214. An elasticity of 0.62 indicates that there is a 0.62% increase in VMT as a result of each 1% increase in state highway lane miles.

¹⁰ *Ibid.*

¹¹ *Ibid.*, p. 205.

¹² *Ibid.*

¹³ *Relationships Between Highway Capacity and Induced Vehicle Travel*, Robert B. Noland, Transportation Research Board Annual Meeting, January 1999.

vehicle travel. The effects of different types of road capacity (urban interstate, urban arterials, rural interstates, rural arterials) were examined separately. In each of these cases, the long-run elasticity was found to be in a range from approximately 0.71 to 0.84.

Hansen, Gillen, and Puvathingal examined the effects of capacity expansion on different types of land development.¹⁴ In this research, residential single-family, residential multi-family, commercial, and industrial building permit activity were statistically related to capacity expansions of eight California corridors that were completed in the 1970 through 1988 period. The statistical technique used controls for such things as regional population growth and economic activity, as well as other factors such as a building freeze imposed by one city in certain years. Thus, the statistical analysis isolates the effect of development induced by the capacity expansion, independent of general and regional development trends.

This study concludes: “[The] results offer strong support for one overriding conclusion: highway capacity expansion stimulates development activity, both residential and non-residential, in the corridors served by the expanded facilities.”¹⁵

Induced Traffic – Transportation Research Board Committee Report

The National Research Council’s Transportation Research Board issued a committee report that examined the effects of road capacity expansion on travel, with special attention to air quality and energy use.¹⁶ The report’s principal results include these mixed conclusions:

The current regulatory focus on curbing growth in motor vehicle travel by limiting highway capacity is at best an indirect approach for achieving emissions reductions from the transportation sector that is likely to have relatively small effects, positive or negative, on metropolitan air quality by current attainment deadlines. Executive Summary, p. 8.

The effects of traffic flow improvements could be positive or negative, depending on offsetting increases in traffic. *Ibid.*

On the other hand, the report also concludes:

...major highway capacity additions are likely to have larger effects on travel and to increase emissions in the affected transportation corridors in the long run unless some mitigating strategy is implemented in conjunction with the capacity addition. *Ibid.*

Finally, the report points out that:

¹⁴ *Freeway Expansion and Land Development: An Empirical Analysis of Transportation Corridors*, Mark Hansen, David Gillen, and Mohnish Puvathingal, Institute for Transportation Studies, UC Berkeley, sponsored by Caltrans Division of New Technology, January 1988.

¹⁵ *Ibid.*, p. 11.

¹⁶ *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, Committee for Study of Impacts of Highway Capacity Improvement on Air Quality and Energy Consumption, Transportation Research Board, National Research Council, 1995. Available at <http://books.nap.edu/books/0309061075/html/index.html>.

Congestion pricing... could mitigate negative effects on emissions from travel growth. *Ibid.*, p. 9.

The body of the report elaborates on these last two conclusions as follows:

...the potential for a highway capacity addition to affect travel decisions depends on the size of travel cost reductions resulting from the expansion project. Capacity additions that provide larger time savings are expected to have a greater effect on travel decisions. Transportation system management actions such as traffic signal retiming, channelization, and other intersection improvements generally have modest effects on travel times and are therefore expected to have modest induced travel effects. Adding lanes to a congested freeway can result in large time savings during peak periods. Larger induced traffic effects along with some shifting of traffic from other time periods might be expected during these periods. P. 149.

Potential increases in traffic from highway capacity additions might be reduced by imposing or raising tolls on the improved facilities. P. 150

The Sunol Grade project will certainly have – absent induced demand effects – large travel cost effects in terms of time savings. Congested travel times during peak periods have been measured at one hour and eight minutes (1:08).¹⁷ Uncongested travel times are 18 minutes (0:18) or less.¹⁸

Induced Traffic – Department of Transport Report

The British Department of Transport also examined induced demand effects.¹⁹ This report concludes quite strongly that induced demand effects must be evaluated in the consideration of new road projects (“schemes”), rather than assuming an unchanging level of traffic (“fixed demand approach”):

...we do not think that continuing to appraise solely at the scheme level using the fixed demand approach is, either intellectually, or in practical terms, acceptable. It is this central conclusion which has led us to make the recommendations in this Report. Executive Summary, p. iv.

The report indicates that:

Induced traffic is of greatest importance in the following circumstances:

- where the network is operating or is expected to operate close to capacity;
- where traveller responsiveness to changes in travel times or costs is high, as may occur where trips are suppressed by congestion and then released when

¹⁷ *Technical Report on the I-680 Traffic Operations Study*, p. 14.

¹⁸ Uncongested travel time calculated at 60 miles per hour.

¹⁹ *Trunk Roads and the Generation of Traffic*, The Standing Advisory Committee on Trunk Road Assessment, HMSO Publications, London, 1994.

the network is improved;

- where the implementation of a scheme causes large changes in travel costs.

This suggests that the categories of road where appraisal needs to be most careful are improvements to roads in and around urban areas, estuary crossing schemes, and strategic capacity-enhancing interurban schemes, including motorway widening. *Ibid.*, p. iii.

Again, these criteria are particularly applicable to the Sunol Grade. While the Sunol Grade is not an “estuary crossing scheme,” it is indeed a “strategic capacity-enhancing interurban scheme,” and, given the relative impassability of the hills between Pleasanton and Milpitas, it does share many characteristics with water crossings such as the Bay Bridge. The Sunol Grade corridor connects two distinct urbanized areas, with a differential concentration of housing and jobs at each end of the corridor. In addition, close alternate routes are not available.

Appendix E. Comparison of Carpool and Express Lane Alternatives

The model described in Appendices B and C is used here to examine four alternatives for the Sunol Grade:

1. **HOV2+**. The planned HOV lane open to two-or-more-person vehicles.
2. **HOV2+, separated**. An HOV lane open to two-or-more-person vehicles, and separated from the general purpose lanes.
3. **HOV2+, separated, SOV buy-in**. An HOV lane open to two-or-more-person vehicles, separated from the general purpose lanes, with excess space made available to single-occupant vehicle (SOVs).
4. **Express Lane, HOV3+ free, separated**. An Express Lane free to three-or-more-person vehicles, with limited access to two-person and single-occupant vehicles.

Table E-1 summarizes the features of each alternative and the performance of each in terms of person-hours of delay in the case where travel demand is 25% greater than existing demand. As discussed in Appendix D, a greater than 40% increase in travel demand can be expected within five years of the Sunol Grade capacity expansion. While it is uncertain how soon a 25% increase in demand will be realized, all indications are that such an increase will occur much sooner than five years.

The four alternatives are described further in the following paragraphs. Then the results are discussed, along with the presentation of detailed calculations.

HOV2+. The first alternative is the currently planned HOV lane, open only to vehicles carrying two or more persons. Any excess capacity in the lane will remain unutilized – there are no provisions in Caltrans’ current plans to allow limited access to any other vehicles. As currently

planned, the HOV lane will not have any special separation from the general purpose lanes. Vehicles will be able to enter and exit the lane at any point. Without barrier separation, the lane cannot be reversed to serve the evening commute. In addition, Caltrans expects the capacity of non-separated HOV lanes to be 1700 vehicles per hour. This is substantially less than the capacity of general purpose lanes. This occurs because merges from the slower-moving general purpose lanes interfere with the smooth flow of traffic in the HOV lane.

HOV2+, separated. The second alternative shows the effect of increasing the capacity of the HOV lane to 2100 vehicles per hour. This can be accomplished by preventing the unimpeded ingress and egress of vehicles to and from the lane. Allowing entry and exit from the HOV lane at only designated points can maintain smoother traffic flow.

HOV2+, separated, SOV buy-in. The third alternative shows the effect of allowing a limited number of single-occupant vehicles to access the HOV lane. This improves the utilization of the lane. Because the number of two-or-more-person vehicles that are allowed to use the lane is not limited, however, the lane can become congested.

Table E-1
Comparison of Alternatives

	HOV2+	HOV2+, separated	HOV2+, separated, SOV buy-in	Express Lane, HOV3+ free, separated
Features				
Unlimited, free access available to...	Two-or-more per car	Two-or-more per car	Two-or-more per car	Three-or-more per car
Limited access available to...	None	None	Solo drivers	Two-or-more per car, solo drivers
Barriers?	No separation	Yes	Yes	Yes
Serves evening commute?	No, not reversible	Yes	Yes	Yes
New lane throughput capability (vphpl)	1700	2100	2100	2100
Results – 25% increase in travel demand				
Person-hours delay:				
General purpose lanes	2874	2180	1503	1453
New lane	1305	749	519	0
Total	4180	2929	2021	1453

Express Lane, HOV3+ free, separated. The fourth alternative operates the new lane as an Express Lane. Three-or-more-person vehicles are allowed free access to the lane – there will not be so many such vehicles that the lane would become congested. A limited number of single-occupant and two-occupant vehicles would be allowed to access the lane for a fee. The fee would be adjusted by time of day so that the Express Lane did not become congested.

Table E-1 shows that the first alternative – Caltrans’ current plan – results in significant person-hours of delay in both the general purpose lanes and the new lane. Delay totals 4180 person-hours in the morning peak period. While this is a significant improvement over existing conditions – 11071 person-hours of delay, as table B-1 shows – it is far from a congestion-free commute. Tables E-2 and E-3 present some of the detailed calculations for the first alternative.

Table E-2 first shows the person arrival rate that results from a 25% increase in travel demand compared to existing conditions. It then shows the mode share for two-or-more-person vehicles. This mode share is calculated to be in equilibrium with the results shown in table E-3; it depends on the relative delay in the general purpose lanes compared with the delay in the HOV lane. The average occupancy of two-or-more-person vehicles is 2.3 persons/vehicle. This allows the calculation of the number of two-or-more-person vehicles, and the remaining single-occupant vehicles. The throughput capability of the general purpose lanes is calculated as described in Appendix B; it depends on the length of the queue. The throughput of the general purpose lanes is the lower of the capability or the demand for the lanes. When the demand exceeds the capability of the lanes, then the queue is calculated, and the minutes of delay. Total delay in the general purpose lanes is 2874 person-hours.

Table E-2
Alternative 1: HOV2+
General Purpose Lanes Delay Calculations

Time	In-creased arrival rate (per/h)	Frac-tion persons HOV2+	HOV2+ arrival rate (veh/h)	GP lanes remaining arrival rate (veh/h)	Through-put capability (veh/h)	Vehicles in queue (veh)	Through-put (veh/h)	Result-ing capa-bility (veh/h)	Time - queue (h:m)	Delay (h:m)	Person-hours of delay (per-h)
5:00		0.365			6300	0			5:00	0:00	
5:30	10019	0.369	1605	6327	6237	45	6237	6237	5:29	0:00	11
6:00	10262	0.383	1707	6337	6004	212	6004	6004	5:58	0:02	61
6:30	12348	0.409	2196	7298	4200	1760	4200	4200	6:15	0:14	288
7:00	8299	0.448	1616	4581	4200	1951	4200	4200	6:34	0:25	700
7:30	6742	0.460	1348	3640	4200	1671	4200	4200	7:02	0:27	929
8:00	5222	0.404	917	3113	5939	258	5939	5939	7:55	0:04	805
8:30	5223	0.365	829	3316	6300	0	3833	6300	8:30	0:00	79
9:00	5238	0.365	831	3326	6300	0	3326	6300	9:00	0:00	0
9:30	5595	0.365	888	3552	6300	0	3552	6300	9:30	0:00	0
10:00	5725	0.365	909	3635	6300	0	3635	6300	10:00	0:00	0
<hr/>											2874

Table E-3
Alternative 1: HOV2+
HOV Lane Delay Calculations

Time	HOV2+ arrival rate	Through-put capability	Vehicles in queue	Through - put	Result- ing capa- bility	Time - queue	Delay	HOV time advantage	Frac- tion persons HOV2+	Person- hours of delay
	(veh/h)	(veh/h)	(veh)	(veh/h)	(veh/h)	(h:m)	(h:m)	(h:m)		(per-h)
5:00		1700	0			5:00	0:00			
5:30	1605	1700	0	1605	1700	5:30	0:00	0:00	0.369	0
6:00	1707	1697	5	1697	1697	5:59	0:00	0:01	0.382	3
6:30	2196	1483	361	1483	1483	6:20	0:09	0:04	0.409	143
7:00	1616	1427	456	1427	1427	6:43	0:16	0:08	0.448	366
7:30	1348	1460	400	1460	1460	7:12	0:17	0:09	0.459	486
8:00	917	1693	12	1693	1693	7:59	0:00	0:04	0.405	302
8:30	829	1700	0	854	1700	8:30	0:00	0:00	0.365	7
9:00	831	1700	0	831	1700	9:00	0:00	0:00	0.365	0
9:30	888	1700	0	888	1700	9:30	0:00	0:00	0.365	0
10:00	909	1700	0	909	1700	10:00	0:00	0:00	0.365	0
										1305

Table E-3 shows the similar calculations for the HOV lane. Again, the capability of the lane depends on the level of congestion (length of queue) in the lane. Total delay in the HOV lane is 1305 person-hours.

Alternative two isolates the effect of increasing capacity of the HOV lane, which would occur if it were separated from the general purpose lanes. By itself, the increase in capacity does lead to a decrease in person-hours of delay in both the general purpose lanes and the HOV lane, as table E-1 shows. Delays in the general purpose lanes are reduced by 24%. Delays in the HOV lane are reduced by 42%.

Alternative three shows the effect of allowing single-occupant vehicles to access otherwise unutilized capacity in the HOV lane. The initial effect here is reduce congestion in the general purpose lanes – there is some excess capacity in the HOV lane that is useful in helping to clear the queue in the general purpose lanes. With reduced congestion in the general purpose lanes, there is less advantage to the HOV lane, so fewer vehicles attempt to enter the HOV lane. Thus, congestion is also reduced in the HOV lane.

Finally, tables E-4, E-5, and E-6 present detailed results for the Express Lane alternative. The Express Lane performs better than the other alternatives because uncongested conditions are maintained in the new lane. This improves throughput, and induces an increase in the mode share of three-or-more-person vehicles, which reduces the number of single-occupant and two-person vehicles attempting to access the general purpose lanes.

Table E-4
**Alternative 4: Express Lane
Mode Share Calculations**

Time	In-creased arrival rate (per/h)	Fraction persons HOV2	Frac-tion persons HOV3+	HOV2 vehicles	SOVs	SOV/ HOV2 occu-pancy	HOV3+ arrival rate (veh/h)	SOV/ HOV2 buy in (veh/h)
5:00			0.127					
5:30	10019	0.238	0.127	1193	6361	1.158	398	1702
6:00	10262	0.238	0.127	1222	6515	1.158	407	1693
6:30	12348	0.220	0.194	1357	7244	1.158	747	1353
7:00	8299	0.209	0.235	867	4614	1.158	609	1491
7:30	6742	0.238	0.127	803	4280	1.158	268	1832
8:00	5222	0.238	0.127	622	3316	1.158	207	1893
8:30	5223	0.238	0.127	622	3316	1.158	207	1893
9:00	5238	0.238	0.127	624	3326	1.158	208	1892
9:30	5595	0.238	0.127	666	3552	1.158	222	1878
10:00	5725	0.238	0.127	681	3635	1.158	227	1873

Table E-5
**Alternative 4: Express Lane
General Purpose Lanes Delay Calculations**

Time	GP lanes remaining arrival rate (veh/h)	Through-put capability (veh/h)	Vehicles in queue (veh)	Through-put (veh/h)	Result-ing capa-bility (veh/h)	Time - queue (h:m)	Delay (h:m)	Person-hours of delay (per-h)
5:00		6300	0			5:00	0:00	
5:30	5852	6300	0	5852	6300	5:30	0:00	0
6:00	6044	6300	0	6044	6300	6:00	0:00	0
6:30	7248	4200	1524	4200	4200	6:17	0:12	256
7:00	3991	4577	1231	4577	4577	6:41	0:18	687
7:30	3250	6300	0	5712	6300	7:30	0:00	510
8:00	2045	6300	0	2045	6300	8:00	0:00	0
8:30	2046	6300	0	2046	6300	8:30	0:00	0
9:00	2057	6300	0	2057	6300	9:00	0:00	0
9:30	2340	6300	0	2340	6300	9:30	0:00	0
10:00	2443	6300	0	2443	6300	10:00	0:00	0
								1453

Table E-6
Alternative 4: Express Lane
HOV Lane Delay Calculations

Time	Express Lane arrival rate (veh/h)	Through-put capability (veh/h)	Vehicles in queue (veh)	Through-put (veh/h)	Resulting capability (veh/h)	Time - queue (h:m)	Delay (h:m)	HOV3+ time advantage (h:m)	Fraction persons HOV2	Fraction persons HOV3+	Person-hours of delay (per-h)
5:00		2100	0			5:00	0:00				
5:30	2100	2100	0	2100	2100	5:30	0:00	0:00	0.238	0.127	0
6:00	2100	2100	0	2100	2100	6:00	0:00	0:00	0.238	0.127	0
6:30	2100	2100	0	2100	2100	6:30	0:00	0:12	0.220	0.194	0
7:00	2100	2100	0	2100	2100	7:00	0:00	0:18	0.209	0.234	0
7:30	2100	2100	0	2100	2100	7:30	0:00	0:00	0.238	0.127	0
8:00	2100	2100	0	2100	2100	8:00	0:00	0:00	0.238	0.127	0
8:30	2100	2100	0	2100	2100	8:30	0:00	0:00	0.238	0.127	0
9:00	2100	2100	0	2100	2100	9:00	0:00	0:00	0.238	0.127	0
9:30	2100	2100	0	2100	2100	9:30	0:00	0:00	0.238	0.127	0
10:00	2100	2100	0	2100	2100	10:00	0:00	0:00	0.238	0.127	0
											0