Improving the Estimation of Potential Travel-Time Savings from HOV Lanes

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Abstract

HOV Lanes have become an important part of regional transportation systems in metropolitan areas across the U.S. and in many other countries. The success of HOV lanes is directly related to the travel-time advantage that they provide to their users. To be successful, the flow in the HOV lane must be maintained at a reasonable speed even when the speeds in the mixed-flow lanes deteriorate significantly from congestion. Generally, the key factor in maintaining good speeds in the HOV lane is a matter of keeping the volume in the lane sufficiently below the capacity of the lane. It is common, however, for the speed in the HOV lane to be well below what would be expected from the volume in the lane when the adjacent mixed-flow lane is seriously congested. In research conducted in California, DKS found that on the most seriously congested freeways, the traditional methods of predicting HOV speed using only the HOV lane volume/capacity (V/C) ratio almost always over-predicted HOV speeds and exaggerated travel time advantages. DKS used data from several heavily congested California freeways to develop a mathematical relationship for estimating HOV lane speed based on the V/C ratio in the HOV lane and the V/C ratio in the adjacent lanes. The new model produced a significant improvement in speed estimates and travel-time advantages. This paper describes the research and the resulting model.

HOV Travel-Time Savings

The primary purpose of a High Occupancy Vehicle (HOV) lane is to give a travel-time advantage to higher-occupancy vehicles and in doing so, induce more people to shift from traveling alone to carpooling, vanpooling and using express bus services that operate on the HOV lanes. By shifting travelers to higher occupancy vehicles, highways can operate more effectively and move more people with existing lanes. Travel time savings on successful facilities are often in the range of ½ to one minute per mile. Some of the travel-time saving for HOV can come from preference given to HOVs at ramp meters at the entry points to a freeway, but maintaining a speed advantage in the HOV lane compared to the adjacent mixed-flow lanes is also generally necessary for success.

In reviewing the performance of individual, non-barrier-separated HOV lane segments in California using observed travel-time data from 2001, a research team from DKS Associates found a pattern that had implications for how future HOV lane travel times might be modeled. Many of the HOV lane segments in areas with heavily congested mixed-flow lanes had segment travel times well in excess of what would be expected given the HOV lane volume/capacity ratio. It appeared that HOV-lane vehicles were traveling slower than they might otherwise because of "side friction" from the heavily congested mixed-flow traffic. The friction might have come from people trying to get into or out of the HOV lane when the speed difference between the mixed-flow lane and HOV lane was significant or may have resulted from people in the HOV lane being afraid to drive significantly faster than the traffic in the adjacent mixed-flow lane traffic. Whatever the cause, the result was HOV lane travel times higher (speeds lower) than what the regional model would predict given the volume of traffic in the HOV lane.

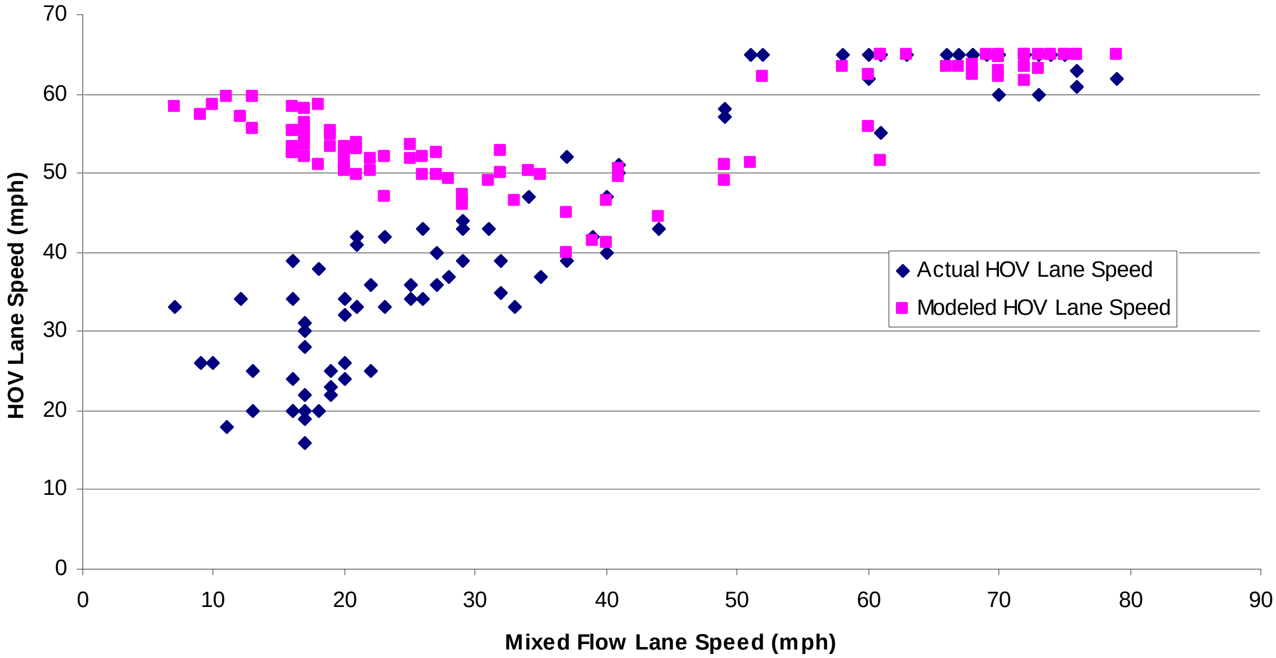
Figure 1 illustrates the issue with sample freeway data from I-210 in Southern California which has a buffer separated, limited entry HOV lane. In this diagram, the modeled HOV lane speeds are estimated using the standard BPR curve used in many transportation models. Using that relationship, the estimated speed is based on the volume/capacity ratio according to the following relationship:

$$S_{HOV} = S_{FF} / (1+0.2(V/.75C)^{6}$$

Where
S_{HOV} = Modeled HOV Lane Speed
S_{FF} = Free Flow Speed
V = Lane Volume
C = Lane Capacity

Figure 1 clearly demonstrates that when the speed in the adjacent mixed-flow lane is below 35 miles per hour, the BPR curve over-estimated the speeds. The slower the mixed –flow lane speed, the greater the error in the speed estimation. For mixed-flow lane speeds over 35 miles per hour, the BPR function provided a reasonable estimation of HOV lane speeds.

FIGURE 1
Comparison of Actual and Modeled HOV Lane Speeds with Mixed-Flow Lane Speed



To address the over estimation of the freeway speeds, the project team used the data available from I-210 to estimate an empirical relationship between the actual HOV lane speed and the difference between the modeled HOV lane speed and the mixed-flow lane speed.

$$S_{HOV2} = S_{HOV} - [-0.67 + 1.02((S_{HOV} - S_{MF})^2 / S_{HOV})]$$

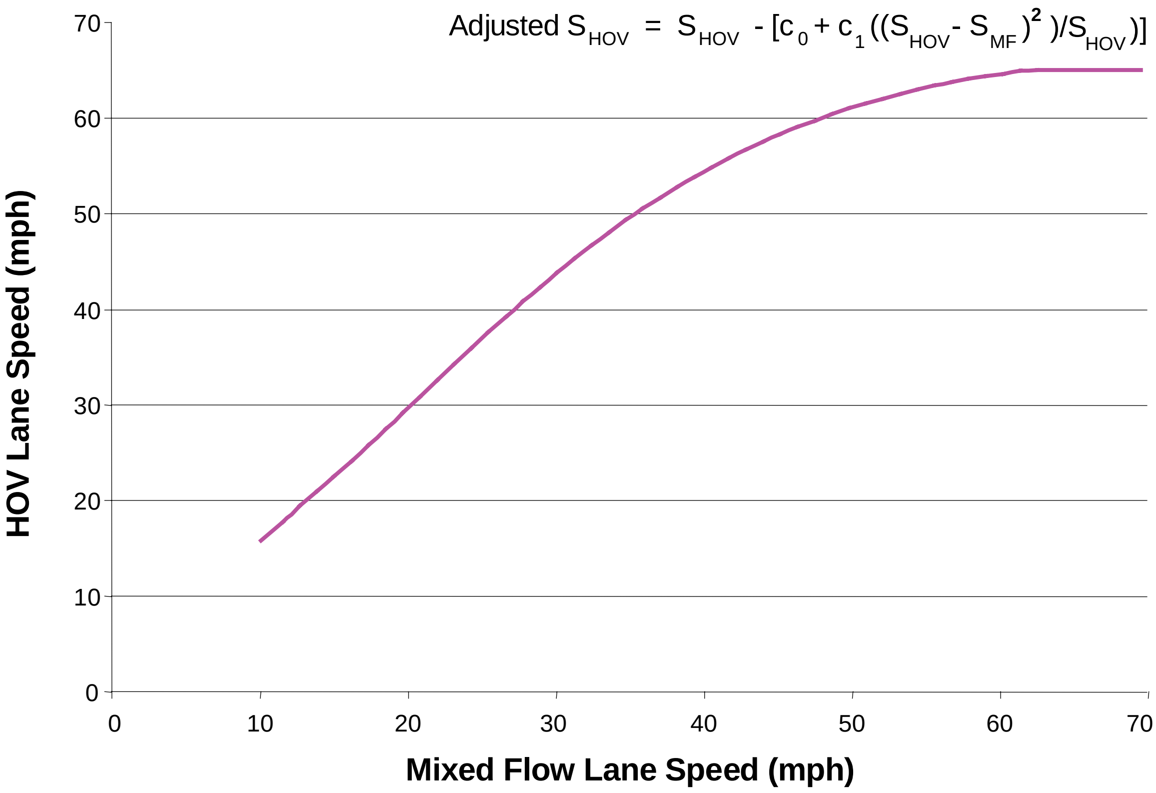
Where: S_{HOV} = speed (mph) in HOV lane, calculated from the BPR speed-flow curve

S_{MF} = speed (mph) in mixed flow lanes

S_{HOV2} =adjusted HOV speed (mph)

The form of the equation was developed by testing a variety of functional forms that would produce a curve with the shape of the observed data. In this formulation, the initial HOV lanes speed, as estimated by the BPR curve, is reduced as a function of the ratio of the square of the difference between the mixed-flow lane speed and the initial HOV lane speed to the initial HOV lane speed. This produces an exponential decay in the HOV lane speed as the mixed-flow lane speed decreases. The parameters were estimated using linear regression. This method produced the relationship plotted in Figure 2. The greater the difference between the uncorrected HOV lane speed and the mixed-flow lane speed, the more the HOV speed would be adjusted downward toward the mixed-flow speed.

FIGURE 2
HOV Lane Speed Correction Function

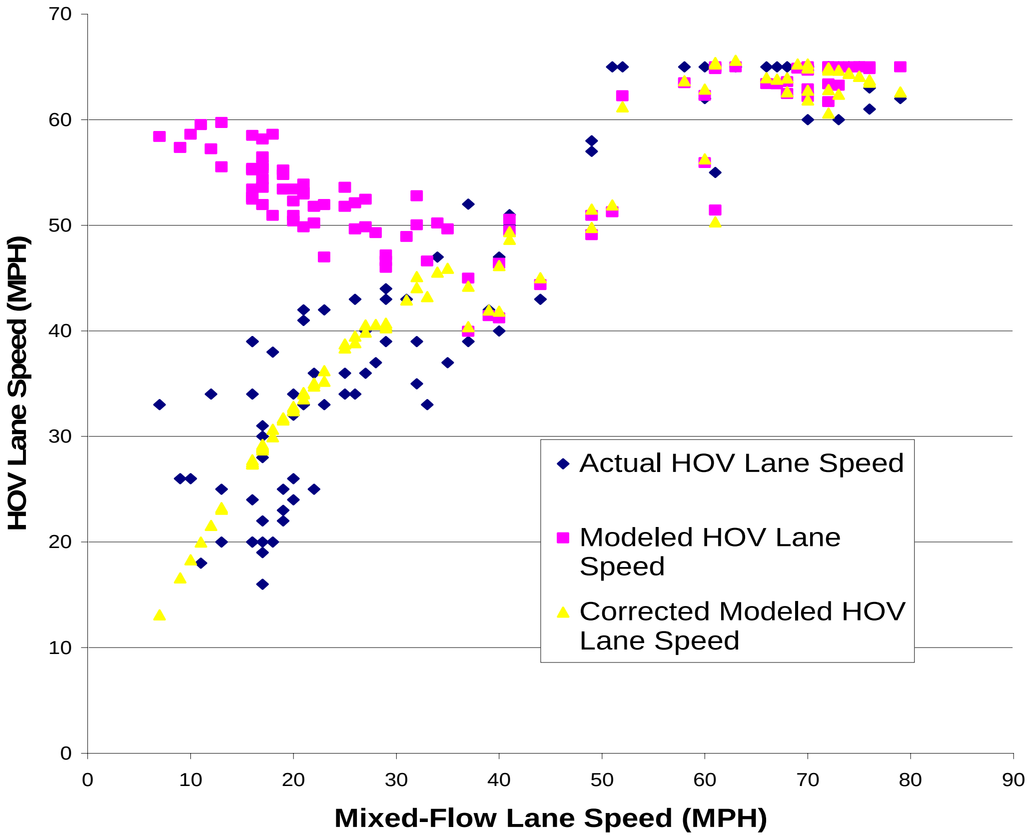


After the relationship was estimated, the corrected HOV lane speeds were estimated for each of the freeway observations. The new corrected speed estimates are compared to the previously estimated speeds and the actual speeds in Figure 3. The figure demonstrates a much closer match with the actual observed speeds for mixed-flow lane speeds over 20 miles per hour. Although the new relationship still over-estimates HOV lane speeds for mixed-flow lane speeds under 20 mile per hour, the new relations provides much better estimates than the BPR function.

Application of the New Speed Estimation Relationship

To apply the results of the HOV Lane Speed Correction, DKS uses a spreadsheet-based, post-processor corridor model that has been used successfully in several key corridor planning projects in the California and the Pacific Northwest. The model allows DKS to import baseline forecast data from a regional model as well as additional data on roadway geometrics to help in producing better estimates of speeds in each lane.

FIGURE 3
Comparison of Actual, Modeled and Corrected HOV Lane Speeds with Mixed-Flow Lane Speed



In an application in the Bay Area of California, DKS applied the relationship to estimate HOV lane speeds for a future forecast year. The results for one segment of freeway for different time slices are illustrated in Table 1. The BPR estimated HOV lane speeds (S_{HOV}) show very little variation ranging from 50 to 57 miles per hour. When corrected to reflect the impact of congestion in the mixed-flow lanes, the estimated HOV speeds ranged from 36 to 50 miles per hour. These corrected speeds were used to supplement a micro-simulation model to support a freeway interchange design.

DKS has also installed within its corridor model a module for applying mode split factors to reflect the issues described above in a pivot-point approach. DKS recently used this approach for the Washington State DOT (WSDOT) to test the potential benefits of transportation demand management (TDM) and land use strategies in reducing congestion in key corridors in the Seattle area[1]. The approach allowed DKS and WSDOT to use reported information on TDM and land use effectiveness to modify regional model forecasts for strategies that the regional model could not model effectively. The same approach has allowed use of results from a significant amount of research on HOV lanes, roadway pricing, and freeway operations and performance to produce more accurate estimates of the travel differences between the alternatives. For a corridor study in the Seattle area, the model was used to test the effect of mixed flow lane speeds on HOV lane speeds using the correction factor described in this paper.

TABLE 1
Example Results from HOV Lane Speed Correction Model

Observation (Time Slices)	**Mixed Flow**	**HOV**	
	S_{Mixed}	**S_{HOV}**	**S_{HOV2}***
	Average Speed (mi/hr)	Calculated Ave. Speed (mi/hr)	Adjusted Ave. Speed (mi/hr)
1	56	50	50
2	52	50	50
3	48	50	50
4	42	50	50
5	36	50	47
6	31	50	43
7	26	50	39
8	21	50	34
9	19	50	31
10	17	50	29
11	15	50	26

* $S_{HOV2} = S_{HOV} - [-0.67 + 1.02*((S_{HOV} - S_{MF})^2 / S_{HOV})]$

Planning Implications

The results of the DKS HOV research have some interesting implications for HOV planning. The first obvious implication is that forecasting of future-year HOV volumes may over-estimate HOV lane utilization when freeway mixed-flow lanes are likely to be most congested. These conditions produce the greatest differential between modeled mixed-flow speeds and modeled HOV lane speeds when standard BPR-type speed estimation models are used. The DKS research suggests that the actual speed differential may be less, resulting in less diversion from driving alone to HOV. The congestion in the mixed-flow lanes may also result in fewer drivers choosing to use the HOV lane because of the difficulty weaving across mixed-flow lanes to HOV lanes.

Other planning implications are a little less intuitive, however. The results may suggest that HOV lanes are most effective when there is a significant difference in the speeds but the speed in the mixed-flow lane is at least 30 miles per hour. This might make a case for considering other

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[1] DKS Associates, Mirai Associates and OTAK, ***Final Report, Modeling TDM Effectiveness: Enhancements to TEEM and Case Studies for the I-405 Corridor***, prepared for the Washington Department of Transportation, Urban Planning Office, February 2005.

freeway management techniques, such as ramp metering, in conjunction with HOV to ensure that a reasonable speed is maintained in the mixed-flow lane.

The research may also make a case for investments designed to reduce the negative impacts of congestion in the mixed-flow lane on the HOV lane speed and the ability of drivers to get to and from the lanes. Although there was no research conducted to determine the effect of barrier separation on HOV lane speed when speeds in mixed-flow lanes are low, barrier separation may reduce the affect of mixed-flow lane congestion on HOV lane speeds as long as the congestion at the entry and exit points to the HOV lane are not heavily congested. The concentration of HOV lane movements in and out of the lane at the limited entry and exit points may result in more conflict with mixed-flow traffic than having continuous entry and exit opportunities.

Suggestion for Further Research

The research reported in this paper is based on analysis of only a single freeway with a buffer-separated, limited entry HOV lane. Since this research was completed, substantially more data are available on the performance of freeways with HOV lanes. The same type of research could be conducted on HOV lanes of different types: continuous entry (no buffer separation), limited entry (buffer-separated) and limited entry (barrier-separated) to determine how the different configurations affect the relationship between mixed-flow lane speed and HOV lane speed.