A Decision Model for Bus-Only and HOV Lanes on Freeways

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ABSTRACT

Bus-only and high-occupancy vehicle (HOV) lanes are two common types of occupancy-based preferential facilities on freeways. Bus-only lanes are designed to give exclusive priority to buses to use certain freeway lanes to improve bus services. Because buses usually use little capacity, it is common to also allow carpools and vanpools to use a bus lane, which gives rise to a HOV lane. This paper describes an effort to develop a decision model for determining if a freeway preferential lane can be justified under the prevailing conditions. The model considers the overall average person travel time under three treatments: mixed-traffic (i.e., no treatment), bus-only lane, and HOV lane. The new HOV modeling capability that comes with the latest version of the CORSIM simulation model was used to estimate the average speeds under different traffic compositions (carpools, vanpools, buses, trucks, and passenger cars), number of lanes, free-flow speeds, and occupancy rates. The simulated data were then used as a substitute for field data in an empirical modeling of relationships between travel speeds and their contributing factors. The estimated speeds then provide input to a decision model for the computation of expected person travel times under the prevailing conditions. The model provides traffic engineers and transit planners a planning tool from which alternatives for freeway preferential lanes can be evaluated.

Keywords: Bus-only lane, HOV lane, simulation, preferential treatment, freeway operations.

INTRODUCTION

Increasing concern for improving the efficiency of roadways in moving people rather than just vehicles has led to the promotion of giving preferential treatments to buses. Bus-only and high-occupancy vehicle (HOV) lanes are two common types of occupancy-based preferential facilities on freeways. Bus-only lanes are designed to give exclusive priority to buses to use certain freeway lanes to improve bus services. Because buses usually use little capacity, it is common to also allow carpools and vanpools to use a bus lane, which gives rise to a HOV lane. The use of preferential facilities is generally justified on the grounds that buses can potentially carry more passengers than automobiles. However, when a lane is taken away from the general-purpose traffic and designated as a bus-only or HOV lane, it can create congestion in other lanes, causing protests by motorists. Such protests are usually exacerbated when a preferential lane is underutilized or perceived to be underutilized, and have led to abandonment of the HOV lane on the Santa Monica freeway in Los Angeles, and more recently, the HOV lanes on I-80 and I-287 in New Jersey.

To maintain the long-term success of preferential facilities, better guidance on conditions that justify bus-only or HOV lanes is needed. Such guidance requires that the expected operational performance of each design alternative be estimated. The operational performance may be measured by travel time, speed, capacity, etc. It is affected by a number of factors, including bus volumes, vehicle volumes, vehicle mix, flow speed, number of lanes, etc. The development of quantitative models that relate these contributing factors to performance measures is thus necessary. Such models allow a proposed preferential lane to be evaluated before implementation, an existing preferential lane to be re-evaluated for possible improvements, and should one become controversial, it can be evaluated objectively. This paper describes an effort to develop a decision model for determining if a freeway preferential lane can be justified under the prevailing conditions. The model considers the overall average person travel time under three treatments: mixed-traffic (i.e., no treatment), bus-only lane, and HOV lane.

EXISTING GUIDELINES

Existing freeway bus preferential treatments range from general guidelines to numerical warrants. Parker and Eburah (*1*) suggested that, for an exclusive bus lane to be feasible, it must not seriously reduce total traffic capacity, yield a net benefit to the community, not involve excessive expenditure, be enforceable, and assist the flow of other traffic where possible. The last criterion particularly recognizes that separation of buses may decrease turbulences in traffic flow and may increase speeds of not only buses, but of the auto traffic in other lanes.

A report prepared by an OECD road research group (*2*) suggested that warrants for bus preferential treatments should be based on peak-period travel, with additional considerations given to air quality and energy conservation goals, downtown parking, transportation development policy objectives, as well as the ability of other streets to carry potentially displaced traffic. Based upon these considerations, the group developed a set of warrants, as given in Table 1, for bus preferential treatments on both freeway and arterial facilities.

TABLE 1 Generalized Applicability of Bus Priority Treatments for Freeway Facilities

Type of Treatment	General Applicability To		"Design Year" Conditions		Related Land Use and Transportation Factors
	Local Bus Service	Limited-Express Bus Service	One-Way Peak-Hour Bus Volume	Peak-hours One-way Bus Passenger Volumes	
1. Busways on special right-of-way		x	40-60	1600-2400	Urban Population 750,000 CBD employment – 50,000, 20 million sq. ft. floor space
2. Busways within freeways right-of-way	x	x	40-60	1600-2400	Freeways in corridor congested in peak-hour
3. Busways on railroad right-of-way		x	40-60	1600-2400	Not well located in relation to service area. Stations required
4. Freeways bus lanes normal flow direction		x	60-90	2400-3600	Applicable upstream from lane drop. Bus passenger time saving should exceed other road-user delays
5. Freeway bus lanes contra-flow		x	40-60	1600-2400	Freeways with six or more lanes, where imbalance in traffic volume permits at least LOS D in off-peak travel directions
6. Bus lane bypass at toll plaza		x	20-30	800-1200	Adequate reservoir on approach to toll station
7. Exclusive bus access ramp to non-reserve freeway or arterial lane	x	x	10-15	400-600	n/a
8. Bus by-pass lane at metered freeway ramp		x	10-15	400-600	Alternate surface route available for metered traffic. Express buses leave freeways to make intermediate stops
9. Bus stops along freeways		x	5-10	50-100 boardings or alightings in peak hour	Generally provide at surface level in conjunction with metered ramp

The HOV Systems Manual (*3*) prescribed the minimum and maximum vehicles for freeway given in Table 2. The minimum values are to ensure that the number of vehicles using a lane on opening day and during the initial phases of a project is high enough to justify the facility and help build support among users, non-users, and the general public, while the maximum values are set to maintain the level of service that provides the travel time savings and reliability of the facility. It is noted that these threshold values are not absolute and should be adjusted for local conditions.

Although existing guidelines include specific threshold values for adopting a preferential treatment, they are not sensitive to the many local factors that might influence the decision. As a consequence, they cannot be used as a design tool. In addition, they are also not based on consideration for the well being of all traffic and are not sensitive to the occupancy rates. Thus, the derived decisions are vehicle-based, rather than person based.

TABLE 2 Operating Threshold Guidelines for Freeway Facilities

Freeway Preferential Treatment	Minimum in vphpl	Maximum in vphpl
Separate right-of-way, bus-only	300-400	800-1,000
Sparate right-of-way, HOV	800-1,000	1,500-1,800
Exclusive two-directional	400-800	1,200-1,500
Exclusive reversible	400-800	1,500-1,800
Concurrent flow	400-800	1,200-1,500
Contraflow, bus-only	200-400	600-800
Contraflow-HOV	400-800	1,200-1,500
HOV bypass lanes	100-200	300-500

OVERALL METHODOLOGY

This study uses the simulation approach to generate data from different input scenarios. The simulation approach was selected for two main reasons:

1. It was believed that the complex interactions among the many variables of interest could not be modeled mathematically.
2. It was not feasible to collect field data that would provide a sufficient sample size for the calibration of empirical models.

Simulated data were used as a substitute for field data in an empirical modeling of relationships between travel speeds and their contributing factors. The estimated speeds then provide input to a decision model for the computation of expected person travel times under the prevailing conditions. The objective of the decision model would be to select the alternative that minimizes the overall person travel time per person per mile. The overall modeling methodology consists of the following five major steps:

1. Select the appropriate measure of effectiveness (MOE) for measuring design effectiveness and the potential contributing factors that are expected to have an impact on the MOE.
2. Develop simulation models to simulate the effects of the contributing factors on the MOE.
3. Establish the empirical relationships between the MOE and the contributing factors.
4. Evaluate the reasonableness of the empirical models and results.
5. Develop a decision model for determining suitable preferential treatment based on the predicted MOE and occupancy rates.

These steps are discussed in greater detail in the following sections.

PERFORMANCE MEASURE AND CONTRIBUTING FACTORS

Typical freeway MOEs include speed, density, travel time, and flow rate. Average speed is chosen as the MOE for this study because it is not only a key measure for assessing the quality of traffic flow on freeways, but it is also a variable for computing travel times. The contributing factors considered include those that are expected to affect average speed. They include passenger car volume, bus volume, truck volume, carpool volume, free-flow speed, and number of freeway lanes.

SIMULATION MODEL DEVELOPMENT

Traffic Simulator

It was first determined that a microscopic simulation model was to be used because of the need to model detailed design features and to visualize traffic animation for model verifications. The CORSIM (CORridor SIMulation) (*4*) simulation model developed by the U.S. DOT was selected for the following reasons:

1. It provides most of the features needed and was readily available to the research team.
2. It is the most widely used and accepted model in the U.S. and the researchers are familiar with the use of the model.
3. Model parameters in CORSIM have been calibrated to the U.S. conditions.
4. It uses the ASCII file format for both input and output files, facilitating the automated execution of multiple simulation runs (see the next section).
5. It allows traffic animation to be visualized.

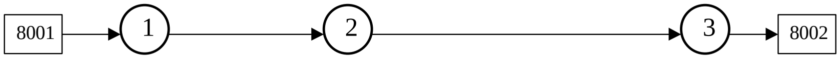
CORSIM represents traffic flow on a roadway system using commonly accepted driver and vehicle behavior models. It can simulate individual transit vehicle operations and control systems on integrated networks containing freeways and surface streets. CORSIM can analyze a wide range of traffic, geometric and control conditions and produces a relatively rich set of performance measures, including travel time, delay, speed, stops, queue time, stop time, queue length and fuel consumption. In addition, CORSIM includes the TRAFVU (TRAF Visualization Utility) program that can dynamically display the actual traffic operations of a simulation mode (*5*). CORSIM first incorporated the capability to model HOV lane(s) in Version 5.0, i.e., the latest version. HOV lane operations are modeled in CORSIM mainly through Record Type 33. CORSIM can model one or more HOV lane of the same type for multiple time periods. The HOV lanes can either be on the left-hand or right-hand side, and can be defined for buses only, carpools only, or both. To model exclusive HOV lane(s) that are barrier or double-line separated, Record Type 19 must be used.

Coding Base Networks

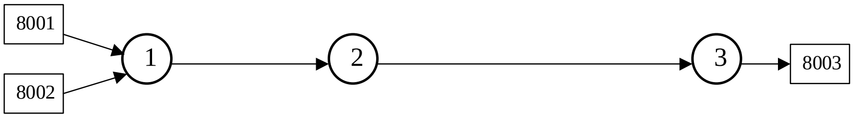
The base networks must first be coded. The base network files are used later to create the input files for the other traffic scenarios. Networks are represented in CORSIM by links and nodes. A link represents a section of roadway and a node is generally used to connect two roadway sections. Figure 1 (a) shows the link-node diagram for three-lane and four-lane facilities. Node 8001 is the entry node that is used to specify the entry volume. For five-lane facilities, because the value for entry volume is limited to four digits, the highest link volume that can be specified is 9999 vph. This value cannot meet the capacity of a five-lane facility. To get around this limitation, a second entry link was added. As shown in Figure 1 (b), entry link (8001,1) is assigned three lanes and entry link (8002,1) is assigned two lanes. Together, these two links allow the total entry volume to exceed 9999 vph.

Since traffic on the section close to the entry link is generally not stable, especially under heavy entry volume, link (1,2) is included so that the unstable traffic can be excluded and will not affect the final output. The TRAFVU animation was observed to determine the required length of this section. The final outputs were extracted from link (2,3), which has a length of one mile. Figure 2 shows a

TRAFVU snapshot for two preferential treatments: one with a HOV-lane (top) and one without (bottom). Note that this figure was created only for illustration purposes, that in the actual simulation, the two treatments are simulated separately. A total of six base networks were created for 3-, 4-, 5-lane freeway (per direction) with and without a preferential lane.



(a) For 3- and 4-Lane Cases



(b) For 5-Lane Case

FIGURE 1 Link-Node Diagrams for Base Networks.

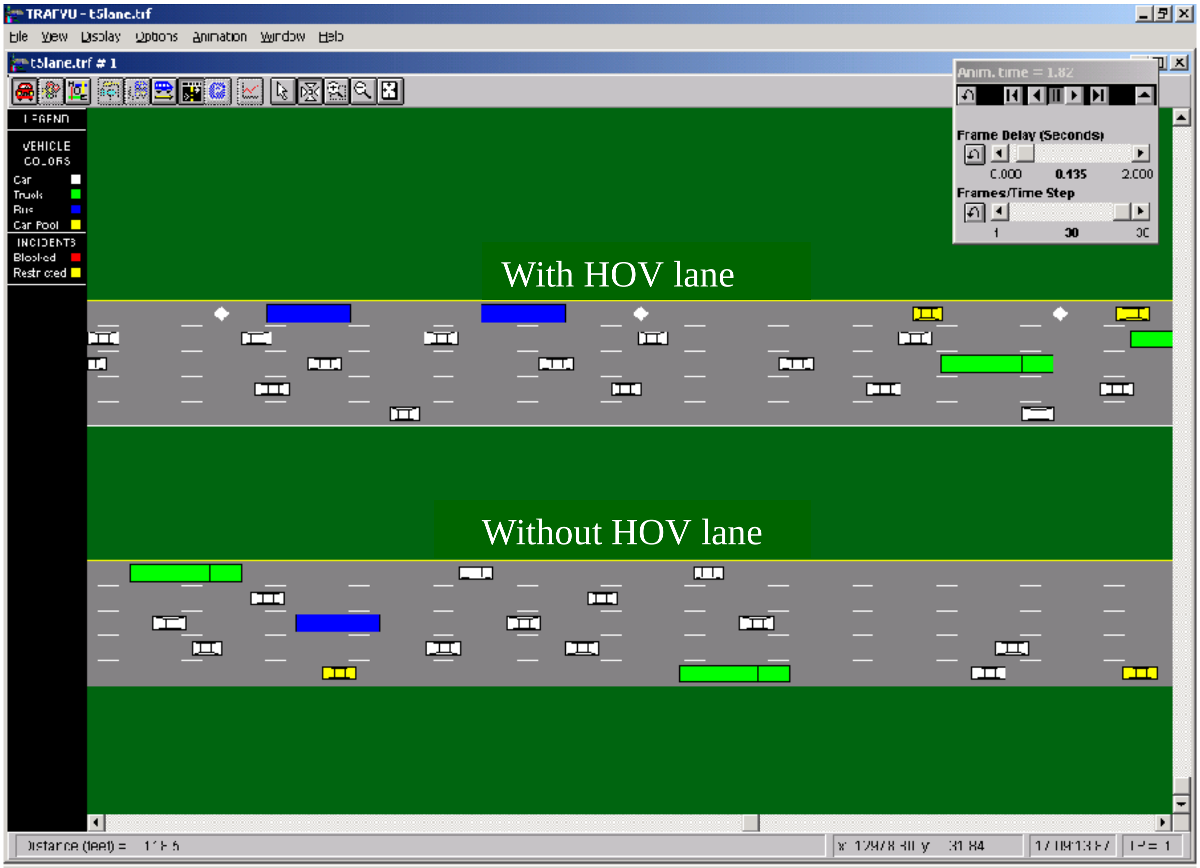


FIGURE 2 TRAFVU Animation.

Simulation Runs

Once the CORSIM base input files were developed, the values for the contributing variables were systematically changed to model different scenarios. The values simulated for each contributing variable are listed in Table 3. The different inputs resulted in a combination of 9,072 simulation scenarios for each base network, or 54,432 scenarios for all six base networks. Because of the stochastic nature of simulation models, each simulation run may produce significantly different results. In order to get a more representative estimate, a number of replications with different random number seeds were performed. Most simulation studies have used between five to ten replications. For this study, five replications were performed for each scenario, resulting in a total of 272,160 simulation runs. The length of simulation time for each run is 30 minutes. Since some of the input combinations result in over-capacity (for example, 6,000 passenger cars and 900 trucks for a three-lane facility), their simulation was not performed.

TABLE 3 Variables Input Values

Contributing Variable	**Input Values**
Total volume excluding buses (for 3-lane)	750, 1500, 3000, 4500, 5400, 6000, 6300, 6600, 6900
No. of passenger cars	Total volume – truck volume – carpool volume
No. of trucks (% of total volume)	0%, 3%, 6%, 9%, 12%, 15%
No. of carpools (% of total volume)	0%, 3%, 6%, 9%, 12%, 15%
No. of buses per hour	40, 90, 180, 300, 450, 600, 720
Free-flow speed	55, 60, 65, 70

Automated Procedure Multiple Runs

Due to the high number of simulation runs, a program was developed to automate the process of performing multiple simulation runs for various scenarios and extracting the appropriate simulation output from each run. In other words, the program performs multiple simulation runs continuously for different combinations of bus volume, non-bus volumes, free-flow speed, etc., and obtains from each run the simulated performance value. The procedure consists of the following steps (*6*):

1. Read the input file for the base network.
2. Modify the base input file for a specific scenario.
3. Save as a new input file.
4. Run CORSIM for the new input file.
5. Read the CORSIM output file and extract related output for the scenario.
6. Repeat steps 2 to 5 for four different random number seeds.
7. Average the output values from each of the five replications.
8. Save all input and output values to a file.
9. Repeat steps 2-8 until all scenarios are simulated.

This automated procedure allows the complete process to be repeated. This is important because several model fine-tunings were needed during the model development process. Note that in step 4, a shell program called RunCOR (*7*) was used to execute CORSIM in the batch mode. RunCOR allowed CORSIM to be executed without the original TSIS shell program.

REGRESSION MODELS

The SPSS statistical analysis package was used to develop the regression equations based on the simulated data. Individual variables were first plotted against average speeds to help identify suitable functional forms. Unlike for linear models, SPSS' non-linear regression procedure does not result in unique model coefficients. The procedure is based on an iterative process that requires a user-specified starting point. Different starting points may result in different model coefficients. Using the coefficient of determination (i.e., R^2 value) as the principal guide, different starting points were attempted for each model. The following three subsections present the models for estimating the average vehicle speeds of the single HOV lane, the mixed lanes adjacent to the HOV lane, and the all-mixed lanes (i.e., without a preferential lane).

Average Speeds of HOV Lane

The regression models for the average speed of the HOV lane, S_1, for different number of lanes were found to be:

$$\boldsymbol{S_1} = \begin{cases} FFS \times e^{-\left(\frac{0.812C}{10000}\right)^{0.842}} & \textit{for 3-lane facility} \qquad R^2 = 0.824 \\ FFS \times e^{-\left(\frac{0.604C}{10000}\right)^{0.799}} & \textit{for 4-lane facility} \qquad R^2 = 0.872 \\ FFS \times e^{-\left(\frac{0.572C}{10000}\right)^{0.878}} & \textit{for 5-lane facility} \qquad R^2 = 0.822 \end{cases}$$

where FFS is free-flow speed and C is number of carpools. The exponential function meets the boundary conditions well in that when the total volume is near zero, vehicles will travel near the free-flow speed. The speed will decrease slowly as the total volume increases and continue to decrease in a decreasing rate. It is interesting to note that the number of buses did not show up as a significant factor that affects the average HOV lane speed. This is because only a practical maximum number of buses (720 vph) was included in the simulated data. This maximum was not high enough to cause a significant speed reduction in the HOV lane. However, when carpools are allowed to use the HOV lane, the average HOV lane speed will be reduced.

Average Speeds of Mixed Lanes Adjacent to HOV Lane

The regression models for the average speed of the mixed-traffic lanes adjacent to the HOV lane , S_2, for different number of lanes were found to be:

$$\boldsymbol{S_2} = \begin{cases} FFS \times e^{-\left(\frac{0.014B+0.075C+1.859T+0.818PC}{10000}\right)^{1.999}} & \textit{for 3-lane facility} \qquad R^2 = 0.923 \\ FFS \times e^{-\left(\frac{0.051B+0.0002C+1.758T+0.620PC}{10000}\right)^{2.417}} & \textit{for 4-lane facility} \qquad R^2 = 0.892 \\ FFS \times e^{-\left(\frac{0.025B+0.00013C+0.544T+0.283PC}{10000}\right)^{1.641}} & \textit{for 5-lane facility} \qquad R^2 = 0.982 \end{cases}$$

where B, C, T and PC are buses, carpools, trucks, and passenger cars, respectively. The coefficients suggest that a truck has a higher impact than a passenger car on the average travel speed. The relatively small coefficients for buses and carpools suggest that, when the HOV lane is over-capacity, some buses or carpools may use the mixed lanes; however, their impact on the average speed is minor compared to the other vehicles.

Average Speeds of All-Mixed Traffic Lanes

The regression models for the average speed of the all-mixed traffic lanes (i.e., no preferential lane), S_3, for different number of lanes were found to be:

$$\boldsymbol{S_3} = \begin{cases} FFS \times e^{-\left(\frac{0.925B+1.183T+0.698C+0.689PC}{10000}\right)^{2.478}} & \textit{for 3-lane facility} \qquad R^2 = 0.893 \\ FFS \times e^{-\left(\frac{0.933B+1.270T+0.572C+0.646PC}{10000}\right)^{3.362}} & \textit{for 4-lane facility} \qquad R^2 = 0.859 \\ FFS \times e^{-\left(\frac{0.735B+1.067T+0.433C+0.444PC}{10000}\right)^{2.906}} & \textit{for 5-lane facility} \qquad R^2 = 0.883 \end{cases}$$

where all the variables are as defined previously. The coefficients suggest that one bus has the impact of about 1.5 passenger cars on the average speed. For trucks, the number is increased to about two. As expected, a carpool has the same impact as a passenger car. The slight difference in their coefficients is due to the regression process and the randomness of simulation.

Comparisons of Average Speeds

Figures 3 to 6 plots the regression models developed for the four-lane case as a function of number of carpools, buses, trucks, and passenger cars, respectively. The free-flow speed is assumed to be 65 mph. For each plot, the variables that are not plotted are each assumed to be a constant value, which are indicated as part of the figure title.

Figure 3 shows that an increase in the number of carpools reduces the HOV lane speed. However, the increase in carpools has less impact on the lanes adjacent to the HOV lane. The reduction in speed in this case may be attributed to the increased weaving of carpool vehicles in and out of HOV lanes. As expected, the number of carpools has no impact on the average speed of the all-mixed lanes (i.e., no HOV lane). Figure 4 shows that an increase in the number of buses reduces the average speed of the all-mixed lanes, but not the mixed lanes adjacent to the HOV lane, since buses only use the HOV lane.

In Figure 5, it can be seen that an increase in the number of trucks will reduce both the mixed lanes adjacent to the HOV lane and all-mixed traffic lanes. However, the impact of trucks is more significant in the presence of HOV facility, since fewer lanes are available for use by trucks. The figure also shows that trucks do not affect the HOV lane since they do not travel on it. Figure 6 shows that an increase in the number of passenger cars reduces the average speeds of both the all mixed lanes and mixed-traffic lanes adjacent to HOV lane, but not the HOV lane.

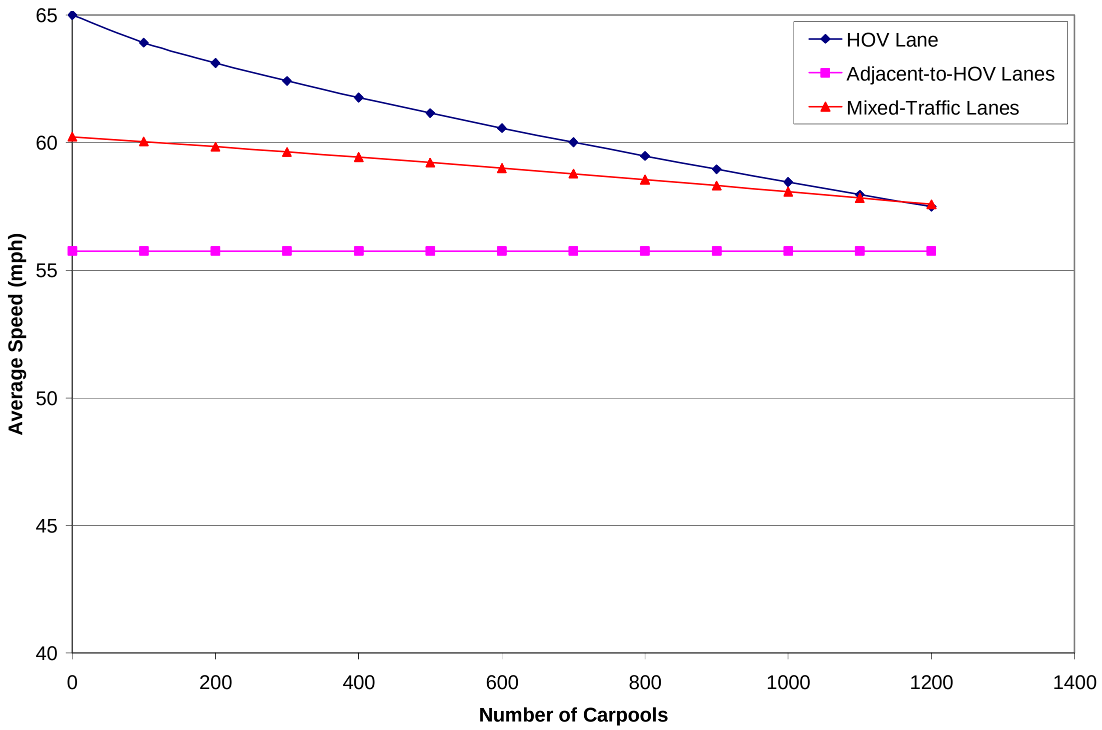


FIGURE 3 Average Speed vs. Number of Carpools.
(Four-Lane; Hourly Volumes: 6000 Passenger Cars, 500 Trucks, and 150 Buses)

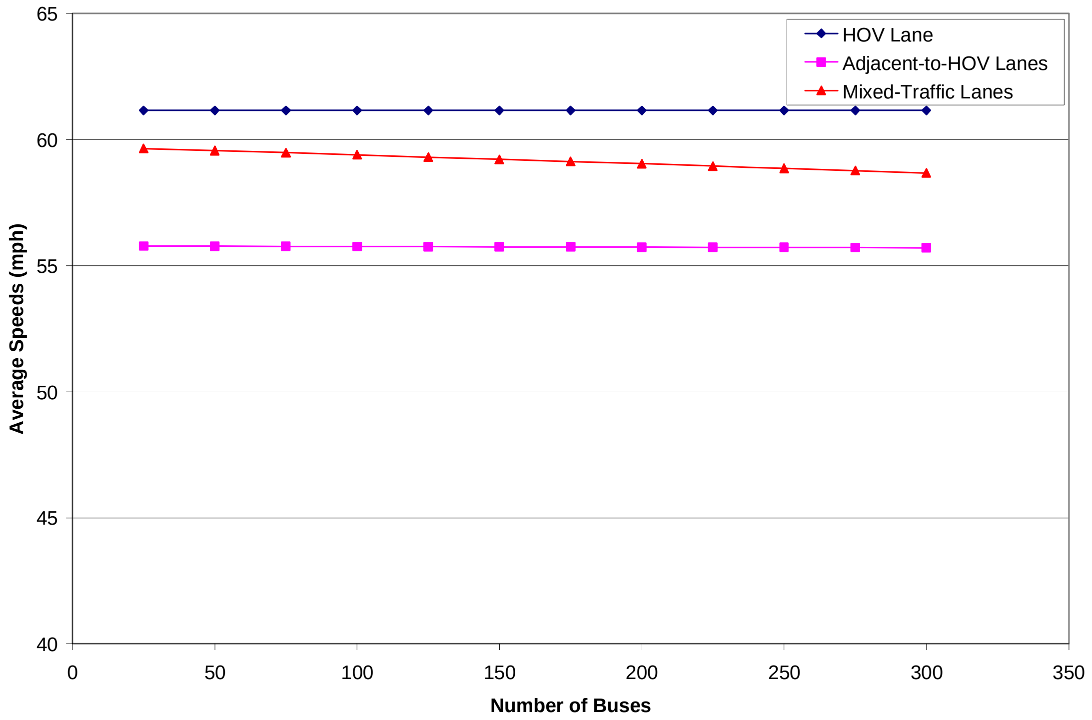


FIGURE 4 Average Speeds vs. Number of Buses.
(Four-Lane; Hourly Volumes: 6000 Passenger Cars, 500 Trucks, and 500 Carpools)

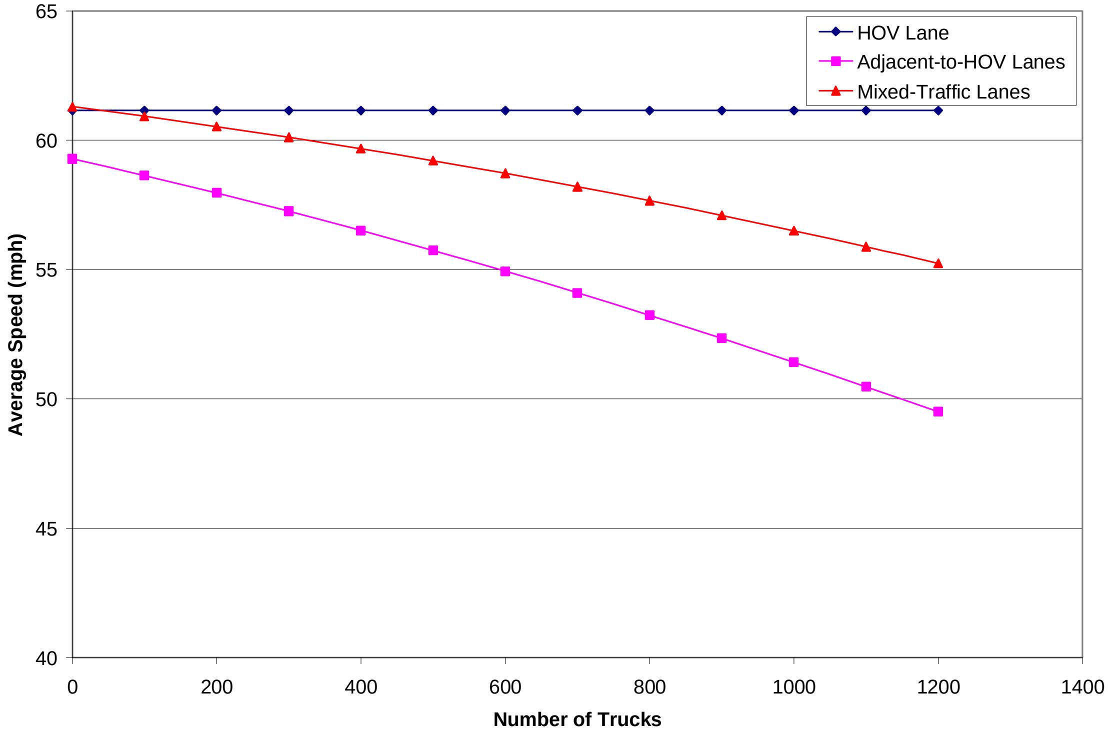


FIGURE 5 Average Speeds vs. Number of Trucks.
(Four-Lane; Hourly Volumes: 6000 Passenger Cars, 500 Carpools, and 150 Buses)

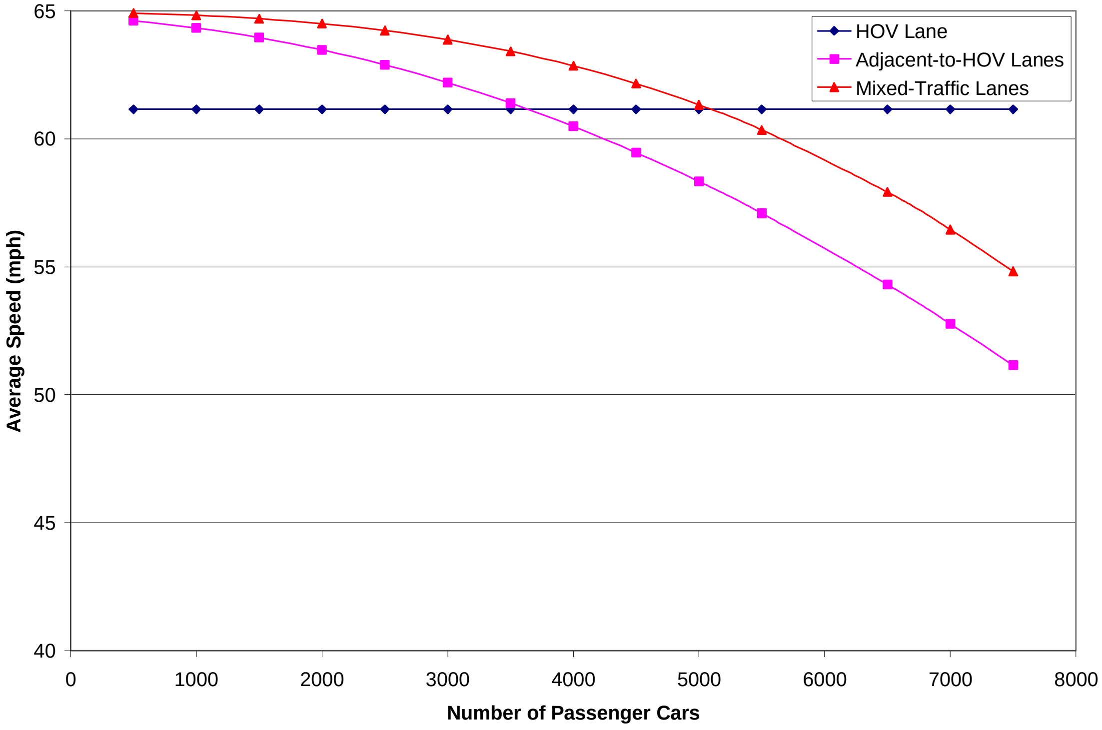


FIGURE 6 Average Speeds vs. Number of Passenger Cars.
(Four-Lane; Hourly Volumes: 500 Trucks, 500 Carpools, and 150 Buses)

MODEL EVALUATION

Ideally, calibrated regression models should be evaluated by field data. However, in many cases, available study sites are either too limited and/or data cannot be easily collected. Even if some data are collected, they are likely to be insufficient to draw conclusions on the validity of the models. In this study, the models were evaluated by comparing their output with those reported in the literature.

Figure 7 shows a comparison of the modeled average speeds for mixed-traffic lanes (S_3) with those predicted by the Highway Capacity Manual (*8*) for basic freeway section and the Bureau of Public Roads (BPR) volume-delay function. The input conditions are 4-lane, FFS = 65 mph, and all passenger cars. The figure shows that the speeds predicted by the model are very much in agreement with those predicted by the BPR function. Unlike the 1985 HCM, the 2000 HCM uses a constant speed for v/c ratios below a certain threshold (up to about v/c = 0.7). While it is well-known that freeway speeds do not drop significantly under free-flow condition, it is only a matter of convenience to assume that the speeds are a constant. In fact, freeway speeds do drop continuously with increasing traffic. This is reflected in the CORSIM simulation model, the BPR function, the 1985 HCM, as well as the data collected from the field (see Figure 8).

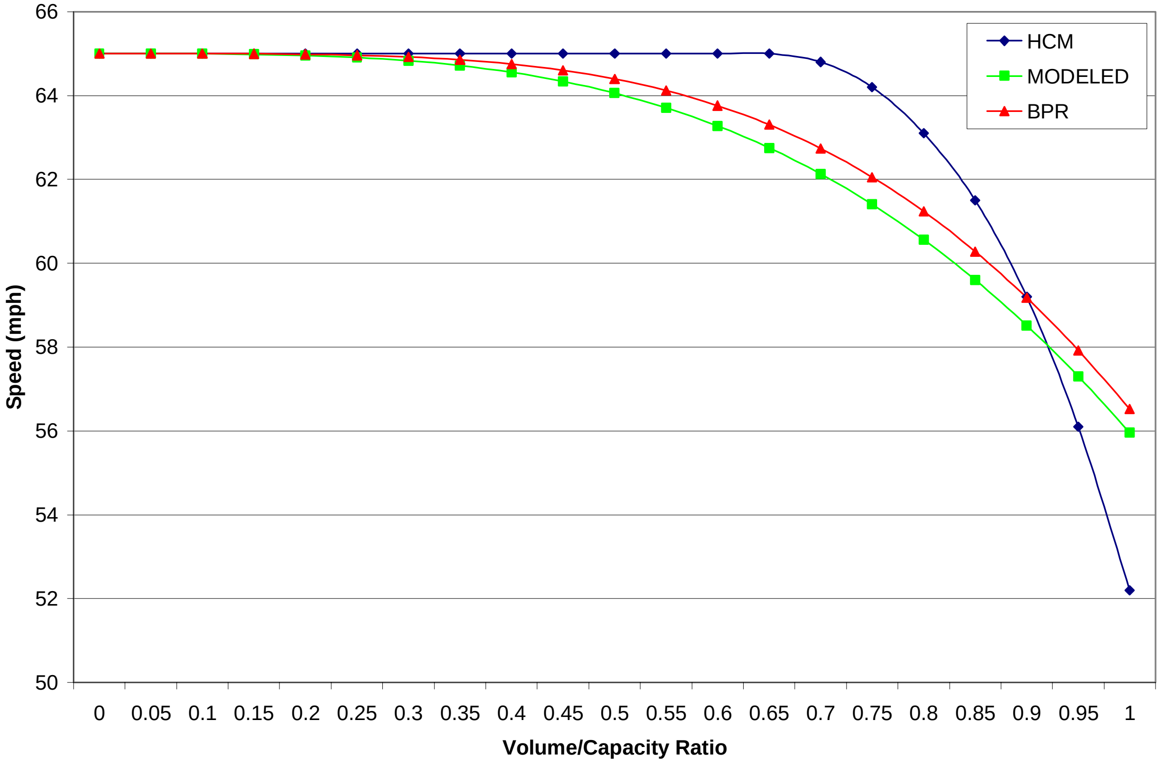


FIGURE 7 Speeds Comparison for Four-Lane Facility.

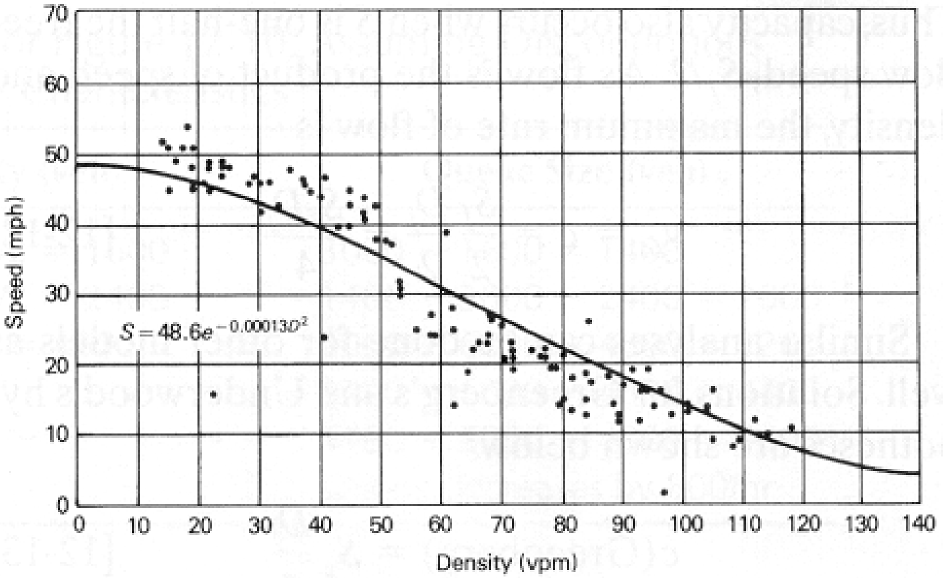


FIGURE 8 Decreasing Speed with Increasing Density (Volume).

DECISION MODEL

The objective of the decision models is to minimize the travel time of all road users of all modes by comparing the person travel times associated with the different design alternatives. The basic decision rule is that a separated lane, either bus-only or HOV, is justified when the resulting average person travel time per mile is less than that of a non-separated facility.

The person travel time (PTT) in seconds per person per mile for the preferential facility can be computed by using the average speeds of the HOV lane (S_1) and the mixed lanes adjacent to HOV lane (S_2) estimated from the regression models, as follows:

$$PTT_{separated} = \frac{3600 \times \left(\dfrac{B \times BO + C \times CO}{S_1} + \dfrac{PC \times PCO + T \times TO}{S_2} \right)}{B \times BO + C \times CO + PC \times PCO + T \times TO}$$

where BO, CO, PCO, and TO are the occupancy rate for buses, carpools, passenger cars, and trucks, respectively, and other variables are as defined previously. Because the occupancy rate for carpools is part of the equation, the decision model may be used to set policy on the minimum carpool occupancy rate.

The person travel time in seconds per person per mile for the non-separated facility is simply computed as follows:

$$PTT_{mixed} = \frac{3600}{S_3}$$

where S_3 is the average speed of all-mixed lanes. This equation assumes that all vehicles travel at about the same speed in the mixed-lane case. This assumption is needed because CORSIM does not allow differential speeds to be specified for different vehicle types. In reality, when there are no preferential treatments, trucks and buses generally travel at slightly lower speeds than passenger cars, with the speed differential diminishing at higher degrees of saturation, as passenger-car speeds begin to be constrained by increasing traffic friction.

APPLICATION EXAMPLES

The application of the decision model is straightforward. For example, given the following information:

- ✓ Five-lane freeway (per direction)
- ✓ Free flow speed = 65 mph
- ✓ Number of passenger cars per hour = 8000
- ✓ Number of carpools per hour = 1250
- ✓ Number of trucks per hour = 1000
- ✓ Number of buses per hour = 125
- ✓ Occupancy rate for passenger cars = 1.3
- ✓ Occupancy rate for carpools = 2.5
- ✓ Occupancy rate for trucks = 1.2
- ✓ Occupancy rate for buses = 50

Step 1. Compute average HOV lane speed (S_1) and average non-HOV lane (i.e., mixed-traffic lanes adjacent to the HOV lane) speed (S_2):

$$S_1 = 65 \times e^{-\left(\frac{0.572 \times 1250}{10000}\right)^{0.878}} = 58.9\ mph$$

$$S_2 = 65 \times e^{-\left(\frac{0.025 \times 125 + 0.00013 \times 1250 + 0.544 \times 1000 + 0.283 \times 8000}{10000}\right)^{1.641}} = 57.4\ mph$$

Step 2. Compute average mixed traffic lane speed (S_3):

$$S_3 = 65 \times e^{-\left(\frac{0.735 \times 125 + 1.067 \times 1000 + 0.433 \times 1250 + 0.444 \times 8000}{10000}\right)^{2.906}} = 55.7\ mph$$

Step 3. Compute average person travel time for with bus lane ($PTT_{separated}$) and without bus lane (PTT_{mixed}) design alternatives:

$$PTT_{separated} = \frac{3600 \times \left(\frac{125 \times 25 + 1250 \times 2.5}{58.9} + \frac{8000 \times 1.3 + 1000 \times 1.2}{57.4}\right)}{125 \times 25 + 1250 \times 2.5 + 8000 \times 1.3 + 1000 \times 1.2} = 62\ seconds / person / mile$$

$$PTT_{mixed} = \frac{3600}{55.7} = 65\,seconds/person/mile$$

Step 4. Decision: Since $PTT_{mixed} > PTT_{separated}$*, a bus lane is justified.*

Another potential application of the decision model is that, rather than given a specific occupancy rate, the analyst may equalize $\text{PTT}_{\text{mixed}}$ and $\text{PTT}_{\text{separated}}$, and then determine the minimum occupancy rate for carpools for policy analysis.

SUMMARY AND CONCLUSIONS

Increasing concern for improving the efficiency of roadways in moving people rather than just vehicles has led to the promotion of giving preferential treatments to buses. Bus lanes and busways are two general types of bus preferential facilities. The use of preferential facilities is generally justified under the grounds that buses can potentially carry more passengers than automobiles. However, when a lane is taken away from the general-purpose traffic and designated as a bus-only or HOV lane, it can create congestion in other lanes, causing protests by motorists. Thus, to maintain long-term success of preferential facilities, better guidance on conditions that justify bus-only or HOV lanes is needed.

A decision model for determining the most suitable freeway preferential treatment under a given set of local conditions has been presented in this paper. The model considers the overall average person travel time and is sensitive to traffic compositions (carpools, vanpools, buses, trucks, and passenger cars), number of lanes, free-flow speeds, and occupancy rates under various preferential treatments (including no preferential treatment). The CORSIM simulation model was used to simulate the different input conditions. The non-linear regression technique was then applied to develop three sets of equations for predicting the average speeds for the HOV lane, the adjacent non-HOV mixed lanes, and the all-mixed traffic lanes. A limited model evaluation was performed by comparing results from a mixed-traffic speed model with those in the Highway Capacity Manual (HCM) and the Bureau of Public Roads (BPR) formula. The results are found to be relatively consistent. The regression models show the following relationships:

1. Average speeds can best be described with an exponential function. At low flow rates, the speeds decrease slowly. At higher flow rates, the speeds decrease at an increasing rate. These results are consistent with those of the HCM and the BPR formula.

2. Unless bus volumes are sufficiently high, the impact of bus volumes on average bus-lane speeds is negligible. This suggests that a bus-only lane usually has extra capacity that can be used by other high-occupancy vehicles.

3. When carpools are allowed to share a preferential lane with buses, the preferential lane speed will be impacted, depending on the number of carpools. The decision model developed can be used to determine an appropriate carpool occupancy rate such that the bus speeds are not adversely affected.

4. The CORSIM simulation model produces freeway passenger car equivalence for trucks and buses that closely approximate those in the HCM.

5. The relative impact of different types of vehicles on a mixed-lane freeway was found to come within the range of vehicle equivalent factor reported in the HCM.

Although the coefficients of the regression models show logical relationships among all the variables considered, the model validation was somewhat limited. Future studies may attempt to further validate the simulated results as more field data and reports become available. In addition, only the leftmost lane is used for HOV lane. Further studies may also attempt to develop models for other configurations of HOV lanes, including the use of the rightmost lane, barrier separation (i.e., zero violation rate), and contra-flow lane.

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