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Predicting Travel Volumes for High-Occupancy-Vehicle Strategies: A Quick-Response Approach

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ABSTRACT

The development of a set of demand and supply models that predict peak-hour travel volumes for high-occupancy-vehicle (HOV) strategies on freeways is described. The demand models were estimated by using a consistent series of before-and-after empirical data from a number of actual HOV facilities located across the United States. Supply models were developed on the basis of speed-volume relationships that estimate changes in running speeds and travel times on the general-purpose lanes for different volume levels and capacity configurations. These models have been incorporated into a set of easy-to-use worksheets to predict equilibrium travel flows of vehicles on the general-purpose freeway lanes and of carpools and buses on the HOV lane or lanes. The models forecast the net change in volume due to mode shift, time of day, trip generation, and route diversion behavior. Consequently, the models provide more information on anticipated travel impacts than can be obtained by using mode-choice models alone. Because the forecasting procedure is designed to provide quick-response results, data requirements are minimal and these data should be readily available to most planning agencies. The accuracy of the forecasting procedure should be interpreted as sketch-planning-level responses that, if conditions warranted, would be subjected to additional and possibly more refined analyses. However, test applications of the prediction procedures described yielded favorable results. Using only data collected before HOV facilities were established, average errors across the HOV sites were less than 4 percent for the nonpriority automobile and HOV bus modes and less than 14 percent for the priority automobile and carpool mode.

Priority treatments for high-occupancy vehicles (HOVs) are transportation system improvements that have proved to be highly cost-effective solutions to meeting urban transportation needs in selected cities across the United States. Given current constraints on constructing new highways in urban areas, such low-capital projects as HOV facilities could become even more popular during the next decade. Although there currently exist computerized models such as the Urban Transportation Planning System (UTPS) that can be used to forecast the travel impacts of alternative HOV treatments, there has historically been little development of approaches that can be used expressly for evaluating HOV strategies in a quick-response time frame.

In this paper the development and testing of a travel forecasting procedure designed specifically for predicting travel volumes resulting from the implementation of priority treatments for HOVs on freeways are described. The procedures developed and described in this paper are intended to be implementable in the face of severe constraints on turnaround time, data availability, and computational resources, while at the same time providing information that is both accurate and easy to obtain. To meet this quick-response capability, forecasts of peak-hour volumes (i.e., for nonpriority automobiles, carpools, and bus transit) can be made by using an ordinary hand-held calculator and a set of worksheets that contain the demand, supply, and equilibrium procedures that were developed.

A comprehensive review of current forecasting procedures revealed that no existing travel demand models have been estimated using actual before-and-after data from the broad cross section of HOV demonstrations and projects supported by the U.S. Department of Transportation since about 1970. Consequently, a consistent set of empirical before-and-after data from HOV sites across the United States was collected and used to estimate models (or relationships) that were packaged in a set of worksheets. These worksheets can be used to make quick forecasts of mode shares and travel volume changes that may be expected from implementing various HOV strategies.

The initial plan was to develop one or more models that could be used to evaluate six different types of freeway or arterial HOV treatments. However, after the data available were examined, it was determined that models could only be estimated for freeway-based HOV sites. Consequently, the travel forecasting procedures reported here were developed to analyze the following four HOV freeway strategies:

1. Dedicate a new or existing lane for bus-only HOV operation;
2. Dedicate a new or existing lane for bus and carpool operation;
3. Allow carpools onto an existing bus-only HOV lane; and
4. Allow carpools with lower occupancy levels onto an existing bus and carpool HOV lane.

DATA COLLECTION FOR MODEL DEVELOPMENT

The principal sources of before-and-after data consisted of evaluation reports of HOV demonstrations that have been implemented during the past 15 years. The first of these large-scale demonstrations began in 1970 with the announcement of the Urban Corridor Demonstration Program. This program was directed toward reducing commuter corridor congestion through the implementation of projects that encourage transit or carpool ridership (e.g., reserved HOV lanes) or that increase the efficiency of existing street systems (1). Later, in 1974, FHWA established Research Project 2D, entitled Priority Techniques for High Occupancy Vehicles, as part of its Federally Coordinated Program (FCP). The objective of the 2D project was to increase the people-moving efficiency of the highway system by (a) applying a variety of techniques for the preferential treatment of HOVs (buses, vanpools, carpools); (b) thoroughly evaluating these techniques with respect to benefits, costs, environmental impacts, and institutional and public acceptance; and (c) providing all information necessary to facilitate wider implementation of the most promising techniques.

Finally, in 1974 UMTA began the Service and Methods Demonstration (SMD) Program to provide a consistent and comprehensive framework within which to formulate, implement, evaluate, and disseminate results of demonstrations including, among other techniques, HOV strategies (2). As a result of the many demonstrations sponsored by these programs, there exists a large body of quasi-experimental observations concerning the impacts of different HOV alternatives. These projects represent a prime source of data that, to date, has not been used in a comprehensive manner either to validate the efficacy of existing travel demand models or to develop new models for the prediction of travel flows resulting from a range of HOV alternatives.

To estimate the proposed HOV demand models, the following set of data was required for at least two time periods for each site: volume of vehicles (or persons) traveling on the general-purpose and priority lanes, travel speeds and times of vehicles on the general-purpose and priority lanes, HOV length, and roadway geometric descriptions (i.e., number of lanes or capacity or both). The first time period represents conditions before the implementation of the HOV treatment in question, whereas the second period reflects conditions approximately 1 year after the implementation of the HOV strategy. If an HOV treatment had been implemented in phases (e.g., bus only with the later inclusion of carpools), additional (before and after) periods were included. Typically, data were tabulated for conditions representing the peak hour in the peak direction. To the extent possible, the morning peak-hour period and direction were used for consistency across HOV sites.

The key before-and-after modal volumes and level-of-service characteristics that were obtained for 12 freeway HOV facilities (or phases) are given in Table 1 (3). Table 2 summarizes the HOV treatments that were already in operation and the new ones implemented. For each site, Table 1 presents the following information:

1. Nonpriority automobile volumes and capacity: Peak-hour (a.m.) volume of automobiles not eligible to use the HOV facilities and capacity of general-purpose lanes for both time periods.
2. Priority automobile volumes: Peak-hour (a.m.) volume of automobiles eligible to use the HOV facility for both time periods.
3. Transit ridership: The volume of bus riders in the morning peak hour who use the HOV lanes in both time periods.
4. Average total travel time: Average total travel time in minutes in general-purpose and HOV lanes for both time periods.
5. Length of HOV lane or lanes in miles.
6. HOV time advantage: The travel time saved by using the HOV facility compared with that by using the non-HOV lanes in the after period (i.e., nonpriority after time minus priority after time).
7. Change in nonpriority in-vehicle travel time (ΔIVTT) from the before to the after period for nonpriority automobiles.
8. Change in priority in-vehicle travel time (ΔIVTT) from the before to the after period for the priority-eligible vehicles (in two instances it includes the change in bus travel time while buses were already on the HOV lane in the before period).
9. Speed: Average speed on the HOV section of roadway for vehicles in the general-purpose and HOV lanes in both time periods.
10. Average trip length: Average trip distance in miles of all users on the HOV roadway.

Seven of the before-and-after sets of data represent the initial start of an HOV priority facility. Four others (Shirley Highway; San Bernardino, phase 2; US-101, phase 2; and I-95, phase 1) represent a change in the HOV facility from bus-only to mixed-mode (carpool and bus) operation. Finally, Banfield Freeway, phase 2, and Miami I-95, phase 2, involved allowing carpools of two or more onto an existing lane that previously allowed buses and carpools of three or more.

DATA LIMITATIONS

The data presented in the evaluation reports for the various HOV sites were not always consistent with the reporting format that was established. Therefore it was sometimes necessary to make adjustments to or estimates from the data presented if no other information was available. These types of calculations were typically required for the following three data items.

Travel Volume

Automobile and transit volumes were frequently presented in the evaluation reports for the full a.m. or p.m. peak periods or both. Therefore to obtain an estimate of the peak 1-hr volumes, the peak-period volumes were divided by typical peaking factors.

Average Total Trip Length

Average trip length was required in some instances to determine average total travel time. When information on trip length was not presented in a report, the agency or organization in charge of the facility was contacted to determine whether the information was available from other sources. In one instance, census information on trips made to the central business district from different zones in the study corridor was used.

Total Travel Time

For almost every site, information was available on the change in travel time in both the general-purpose and HOV lanes because of the implementation of the HOV project. This information was useful in determining the before or after total travel times or both if these data were not otherwise available. For example, if a total travel time estimate was available for the before period but not for the after period, the data on travel time change were used to estimate total travel time for the after period. When neither the before nor the after travel time was reported, an estimate of one value was made using average trip length and speed, and the value for the second time period was computed using the known change in travel time.

DEMAND MODEL DEVELOPMENT

The first consideration in estimating the various HOV demand models was the specification of the (dependent) variable being forecast, that is, whether travel volumes for each mode should be expressed in terms of person or vehicle volumes. The advantage of using persons is that one can examine directly the peak-hour person throughput of a given freeway for different types of HOV strategies. However, the major drawback of this approach is in travel equilibration on the general-purpose lanes, because highway supply relationships are expressed in terms of vehicles. Consequently, it was decided to use vehicles per hour as the measure of travel volume for various classifications of automobiles but to use person trips for bus transit, because equilibration is not an issue in predicting bus demand.

For each mode (nonpriority automobile, priority-eligible automobile or carpool, and HOV bus), models were estimated based on both linear and product specifications of the independent variables. In addition, volumes and level-of-service variables were entered by using either absolute differences or relative differences. Although one functional form did not dominate the others for all HOV sites, the model form that produced the most favorable results for all modes can be expressed as follows:

$$(V_1^m - V_0^m)/V_0^m = a_0 + \sum_i a_i[(T_1^i - T_0^i)/T_0^i] \quad (1)$$

where

V_0^m = peak-hour volume during before period for mode m,
V_1^m = peak-hour volume during after period for mode m,
T_0^i = travel times during before period for modes i to m,
T_1^i = travel times during after period for modes i to m, and
a_0, i = calibration coefficients.

In the following sections results are presented of travel demand models estimated using Equation 1 for the nonpriority automobile, priority automobile, and priority bus modes.

Nonpriority Automobile Model

In Table 3 the parameter estimates, t-statistics, and associated regression results for the nonpriority automobile model are presented. All signs for the parameter estimates are correct and all are significant at the appropriate levels. The R^2 for the entire model is 0.98, with an F-ratio significant at the 99 percent level.

A generalized least-squares estimation procedure was used for model estimation. Basically, this entailed multiplying all variables for each site by the square root of the sum of the travel volumes from the before and after periods. This procedure was used initially because it was suspected that variances in peak-hour volumes are less as travel volumes increase.

In Table 3 the percentage change in total travel time for nonpriority automobiles [i.e., $(T_1^{npa} - T_0^{npa})/T_0^{npa}$] is represented by NPA-TT. Similarly, the percentage change in travel time for two-person carpools is CP2-TT. If two-person carpools are not allowed onto the HOV lanes, this variable will take on the same value as that of NPA-TT. The percentage change in total travel time for carpools of three or four or more persons is CP3/4-TT. Again, the value of this variable will be the same as that of NPA-TT if these carpools are not allowed to use the HOV lanes; alternatively, they will have different values if carpools of three or four or more are already on, or will be allowed on, the HOV lanes. The percentage change in total travel time for buses that are already on, or will be allowed on, the HOV lanes is Bus-TT. The variable that reflects the percentage change in capacity on the general-purpose lanes made available in the after period for use by nonpriority automobiles is the eligibility factor (EFCTR), which is computed as follows:

$$\text{EFCTR} = (L_1^{GP}/L_0^{GP}) \cdot [(V_0^{npa} + V_0^{pa} + 2B_0^{peb})/V_0^{npa}] \quad (2)$$

where

L_0^{GP} = number of general-purpose lanes in the before period,
L_1^{GP} = number of general-purpose lanes in the after period,
V_0^{npa} = peak-hour volume of nonpriority automobiles in the before period,
V_0^{pa} = peak-hour volume of priority-eligible automobiles in the before period, and
B_0^{peb} = number of buses eligible to move to HOV lanes.

If no automobiles (carpools) or buses are allowed to move to the HOV lane and the number of general-purpose lanes does not change, EFCTR will equal 1.0. If, for example, 10 percent of the total number of

TABLE 1 Summary of Key Data for Freeway HOV Sites *(3)*

	Volume (vehicles per hour)								Avg Travel Time by Lane (min)				
	Nonpriority Automobiles				Priority Automobiles		Transit Ridership (persons per hour)		General Purpose		HOV		HOV Length (miles)
HOV Facility	Before	Capacity	After	Capacity	Before	After	Before	After	Before	After	Before	After	
Shirley Highway	4,896	5,880	5,126	5,880	195	758	7,900	8,756	56.2	58.3	37.5	38.3	9.
San Bernardino													
Phase 1	7,300	7,500	7,300	7,500	NPA	NPA	402	1,017	44.8	45.3	NPL	36.9	7.
Phase 2	7,067	7,500	7,277	7,500	299	576	2,490	2,708	45.7	46.1	34.0	35.3/ 34.0[a]	7/11[a]
US-101													
Phase 1	5,314	5,558	5,330	5,616	NPA	NPA	3,370	3,572	35	35	NPL	32.2	3.8
Phase 2	5,125	5,616	5,333	5,616	205	288	3,572	3,686	35	33.1	32.2	32.2	3.8
Banfield Freeway													
Phase 1	3,713	3,900	3,845	3,900	37	180	340	570	21.1	21.1	NPL	19.7	3.3
Phase 2	3,161	3,900	3,793	3,900	530/ 178[b]	1,107/ 163[b]	628	657	22.7	21.4	20.9	20.9	3.3
I-95, Miami													
Phase 1	6,145	7,200	6,416	7,200	170	309	274	314	36.9	34.5	33.4	31.3/ 32.9[a]	7.5
Phase 2	5,170	7,200	5,880[c]	7,200	1,246/ 309[b]	1,357/ 246[b]	314	352	34.5	34.7	31.3/ 32.9[a]	31.3/ 32.9[a]	7.5
Southeast Expressway													
1977	5,504	7,000	4,306	5,300	388	641	2,000	2,124	35	43	NPL	25.0	8.
1971	4,554	5,300	4,201	5,300	NPA	NPA	2,152	2,454	35	30.5	NPL	23.0	8.4
I-495, Lincoln Tunnel	2,324	5,200	3,227	5,400	NPA	NPA	21,868	26,092	70	68	NPL	60	2.5

Note: NPA = no priority automobiles included in HOV treatment. Numbers not rounded off to significant digits. NPL = no priority lane.
[a] Priority automobile or priority bus.
[b] Two-occupant or three-occupant carpool.
[c] High violation rate.

TABLE 2 HOV Treatment for Before and After Time Periods

	HOV Treatment	
HOV Facility	Before Period	After Period
Shirley Highway	Bus only	Carpools of four or more added
San Bernardino		
Phase 1	No priority	Bus only
Phase 2	Bus only	Carpools of three or more added
US-101		
Phase 1	No priority	Bus only
Phase 2	Bus only	Carpools of three or more added
Banfield Freeway		
Phase 1	No priority	Carpools of three or more and buses
Phase 2	Buses and carpools of three or more	Carpools of two or more added
I-95 Miami		
Phase 1	Bus (on NW 7th Avenue)	Buese and carpools of three or more added to I-95
Phase 2	Buses and carpools of three or more	Carpools of two or more added
Southeast Expressway		
1977	No priority	Buses and carpools of three or more
1971	No priority	Bus only
I-495, Lincoln Tunnel	No priority	Bus only

TABLE 3 Nonpriority Automobile Model: Regression Results

Variable	Parameter Estimate	t-Statistic	Level of Significance
Constant	-0.916	10.5	0.01
NPA-TT	-1.053	-3.3	0.01
CP2-TT	+1.190	+3.5	0.01
CP3/4-TT	+0.122	+1.4	0.10
Bus-TT	+0.278	+3.8	0.01
EFCTR	+0.949	+12.1	0.01

Note: NPA-TT = percentage change in total travel time for nonpriority automobiles, CP2-TT = percentage change in total travel for two-person carpools, CP3/4-TT = percentage change in total travel time for carpools of three or four or more, Bus-TT = percentage change in total travel time for buses, EFCTR = eligibility factor.

Summary statistics: F-ratio = 53.1, significance = 0.01, R^2 = 0.98, DFE = 6, MSE = 0.0007.

automobiles using the general-purpose lanes in the before period become eligible to use the HOV lanes, EFCTR will equal 1.11. If one of four general-purpose lanes is taken away for use by HOVs, the value of EFCTR will be reduced to 75 percent (i.e., 3 ÷ 4) of its value if the lane were not taken away. Thus, this variable controls for site-to-site differences in the percentage of vehicles from the before period that become eligible to use an HOV facility during the after period. In addition, the variable reflects the major supply effects due to using a general-purpose lane only for HOV vehicles.

Priority Automobile Model

Table 4 gives the parameter estimates, t-statistics, and associated regression results for the priority automobile models that were obtained by using a generalized least-squares estimation procedure. All parameter estimates have the correct sign and all are significant (PA2-TT is, however, only significant at the 0.12 or 88 percent level). The respective percent changes in total travel time for two- or three-or-four-or-more person automobiles that are already on or will be allowed on the HOV facility are PA2-TT and PA3/4-TT. Thus, the model or models shown in Table 4 can be used to forecast volumes for

TABLE 4 Priority Automobile Model: Regression Results

Variable	Parameter Estimate	t-Statistic	Level of Significance
Constant	-0.2	-0.6	0.28
PA2-TT × [Q]	-6.7	-1.4	0.12
PA3/4-TT × [1 - Q]	-7.7	-4.1	0.01
Bus-TT	+4.8	+2.3	0.03

Note: PA2-TT = percentage change in total travel time for two-person priority automobiles, PA3/4-TT = percentage change in total travel time for three-or-four-or-more-person priority automobiles, Bus-TT = percentage change in total travel time for buses.

Summary statistics: F-ratio = 8.1, significance = 0.02, R^2 = 0.87, DFE = 5, MSE = 0.231, where Q = 1 for two-person priority automobiles and Q = 0 for three-or-four-or-more-person priority automobiles.

Travel Time (min)			Speed by Lane (mph)				One-Way Avg Trip Length (miles)	No. of Buses per Hour	
HOV Time Advantage (after)	Nonpriority ΔIVTT	Priority ΔIVTT	General Purpose		HOV				
			Before	After	Before	After		Before	After
20.0	+2.1	-17.9/ + 0.8[a]	19.0	17.7	55.5	51.5	12.4	176	194
8.4	+0.5	- 7.9	25.4	24.7	NPL	49	19.8	10	45
10.8	+0.4	-10.4	24.2	23.6	49	55/ 49[a]	19.8	81	81
2.8	0	- 2.8	30.0	30.0	NPL	47.1	16	86	94
0.9	-1.9	- 2.8	30.0	40.0	47.1	47.1	16	94	97
1.4	0	- 1.4	38	37.9	NPL	51.5	7	10	20
0.5	-1.3	- 1.8	33	42	47	46.7	7	20	22
3.2/ 1.6	-2.4	- 5.6/ - 0.5[a]	33.2	40.2	44.7	56.6/ 46.7	15.7	10	10
3.4/ 1.8	+0.2	- 3.2	40.2	39.4	56.6/ 46.7	56.6/ 46.7	15.7	10	10
18	+8.0	-10.0	21.0	15.5	NPL	37.2	15	50	54
7.5	-4.5	-12.0	23	29	NPL	50.4	15	57	65
8.0	-2.0	-10.0	10	11.5	NPL	30	25	497	597

carpools that are already on the HOV facility or that will become eligible to use the facility in the after period.

If the model is being used to forecast the number of carpools of three or more persons that will be using the HOV lanes, the variable PA2-TT x [Q] is deleted (or set equal to zero). Conversely, if the model will be used to forecast the volume of two-person priority-eligible automobiles, the variable PA3/4-TT is set equal to zero. (Note: This model cannot be used to forecast the volume of two- or three-or-four-or-more-person carpools that will be traveling on the general-purpose lanes in the after period.)

Because the coefficient of the three-or-four-or-more-person travel time variable is larger than that for two-person carpools, the model indicates that allow- ing carpools of three or more onto the HOV lanes will lead to a larger percentage increase in the volume of carpools of three or more relative to the percentage increase in carpools of two or more if these are granted access to the HOV facility. (Note that although this is true in percentage terms, it may not always be true in absolute terms, because the volume of two-person automobiles is usually much greater than the volume of three-person automobiles.)

The magnitudes of both carpool travel time coefficients (which are related to direct travel time elasticities) are much larger than those derived from traditional or contemporary mode-choice studies. The reason for this is that the priority automobile model is capturing the effects of trip generation, time of day, and route diversion changes as well as modal choice. Thus, a model that examined only mode-choice effects would seriously underpredict the actual volume of carpools on the HOV facility.

The variable Bus-TT is the percentage change in bus travel time between the before and after periods. Note that its magnitude is about two-thirds the size of the carpool travel time coefficients. If buses are already on the HOV facility and the policy being examined is to allow carpools onto the facility, the value of this variable will normally take on a value of zero (assuming, as is typically the case, no degradation in travel speeds on the HOV facility), and the percentage change in the volume of carpools will be a function of the percentage change in carpool travel times. However, if buses and carpools are being granted the use of the HOV facility at the same time (i.e., the facility did not exist in the before period), the model indicates that the percentage increase in carpool volume will be reduced by between one-third to one-half (depending on the size of the travel time savings) compared to the case in which carpools only were granted access. Again, this appears appropriate, because the bus mode will also be competing for some of the travelers who may wish to use the HOV facility.

Priority Bus Models

After alternative specifications for the priority bus model had been evaluated, it was determined that the most appropriate procedure for modeling changes in bus ridership was to use different variable specifications, depending on whether buses or carpools or both are allowed onto the HOV lanes and whether bus supply is determined exogenously or endogenously. A single model specification does not adequately explain the change in transit ridership for both bus-only and bus-or-carpool strategies.

In Table 5 the parameter estimates, t-statistics, and associated regression results are presented for the priority bus models that were estimated using a generalized least-squares estimation procedure. As indicated, model A is used when only buses will use the HOV lane and bus supply is determined endogenously or as a direct result of the HOV time savings. The one variable that was found to be significant was Bus-TT, the percentage change in bus travel time. In effect, the estimation process revealed that changes in nonpriority automobile travel time have little or no explanatory power compared with changes in bus travel time. Because of the small sample size, however, the coefficient estimate is only significant at the 83 percent level. Unfortunately, consistent data on other factors (besides travel times) that could affect bus ridership were not readily available.

Model B is used when only buses will use the HOV lane and supply is determined exogenously or apart from the ridership change expected just from the HOV

TABLE 5 Priority Bus Models: Regression Results

Model	Variable	Parameter Estimate	t-Statistic	Level of Significance
A	Bus-TT	-1.404	-1.1	0.17
B	Bus-TT	-0.308	-2.3	0.07
	Bus-No.	+0.422	26.7	0.01
C or D	Constant	+0.227	1.2	0.14
	PA2-TT × [Q]	+1.710	0.5	0.30
	PA3/4-TT × [1 - Q]	+0.435	0.5	0.30

Note: A = bus only on HOV lane (supply determined endogenously), B = bus only on HOV lane (supply determined exogenously), C = bus and carpools of three or more or four or more on HOV lane (Q = 0), D = bus and carpools of two or more on HOV lane (Q = 1). Bus-TT = percentage change in total travel time for buses, Bus-No. = percentage change in the number of peak-hour buses, PA2-TT = percentage change in total travel time for two-person priority automobiles, PA3/4-TT = percentage change in total travel time for three-or-four-or-more-person priority automobiles.

Summary statistics are tabulated as follows:

Parameter	Model A	Model B	Model C or D
F-ratio	1.2	505.1	1.1
Significance	0.35	0.01	0.46
R^2	0.28	0.99	0.44
DFE	3	2	4
MSE	0.587	0.002	0.066

time savings (e.g., for phase 1 of the San Bernardino project, the El Monte bus terminal was constructed, and in the after period, the number of buses per hour was increased by 350 percent, from 10 to 45). The two variables, percentage change in bus travel time and percentage change in the number of peak-hour buses, have the correct sign and are significant at appropriate levels. [The bus supply variable (Bus-No.) representing the percentage change in the number of peak-hour buses was not used in the other models because of concern for simultaneity. This occurs because bus supply is highly correlated with the dependent variable, bus passengers.]

Model C has a constant and a term for the percentage change in total travel time for priority automobiles with three or four or more persons. Consequently, this model is used when buses and three-or-four-or-more-person carpools are allowed onto the HOV lane. Model D has the same constant but uses the percentage change in travel time for two-person priority automobiles to forecast the volume of bus passengers when buses and two-person carpools will be using the HOV lane. Although the signs for all variables are correct, the significance levels are lower (70 percent) than those typically desired. Thus, the higher standard errors for these coefficients imply greater variances in the forecast of percentage change in bus riders. However, in many instances, the percentage change in bus ridership is relatively small (especially compared with changes in carpools); thus the effects of these larger variances are partially negated.

Unlike automobile and carpool volumes, changes in the volume of bus users are more likely to be dependent on many more site-specific characteristics in addition to changes in level of service (as represented by total travel time changes). Some of these other factors, which are difficult to incorporate in a sketch-planning model, would include average bus headways, average waiting and transfer times, characteristics of bus area coverage or route network, and provision of fringe parking lots for park-and-ride express bus service. Thus, the analyst is reminded that although the priority bus models may provide forecasts that reflect average conditions observed at other HOV sites, the results may not be the most applicable to the HOV facility being evaluated. In such instances, more complex procedures may be required to predict ridership on HOV buses.

SUPPLY MODEL DEVELOPMENT

Commensurate with the level of detail of the demand models, a supply model was developed to estimate average running speed and thus travel time changes for different volume levels (and possibly capacity changes) on the general-purpose lanes. The model was based on the Bureau of Public Roads and FHWA speed-volume relationship normally used in traffic assignment models (4). This relationship can be expressed in general terms as follows:

$$T_1 = T_0 \, [1 + a(V/C)^b] \qquad (3)$$

where

T_1 = travel time in time period 1,
T_0 = travel time at zero volume (or under free-flow conditions),
V = highway traffic volume,
C = capacity of highway, and
a,b = model coefficients.

For the 12 HOV data sets used in developing the demand models, it was observed that traffic on the general-purpose lanes in the before period was operating either at or near capacity (service level E) or, more commonly, under force-flow conditions (service level F). One of the key questions is whether (and how) these service levels will change, given the implementation of a particular HOV strategy. By analyzing before-and-after service levels for various HOV freeway facilities, it was determined that force-flow conditions continued in the after period when (a) a general-purpose lane was taken away or (b) the number of general-purpose lanes did not change but a bus-only HOV lane was implemented. When the number of general-purpose lanes remained the same and carpools were allowed onto the HOV lane or lanes, traffic on the general-purpose lanes either continued operating under force-flow conditions or began operating under free-flow conditions. These observations, therefore, were incorporated into a straightforward procedure for computing supply changes due to various HOV strategies on freeways.

MODEL TESTING

The demand and supply models described in the foregoing have been incorporated into a set of seven worksheets that can be used in a sequential and if necessary iterative fashion to predict equilibrium travel volume resulting from any one of four types of HOV strategies. The flowchart in Figure 1 highlights the major activities for each worksheet. [Additional details on the use of the worksheets are presented in the User's Guide (5).]

With these worksheets, forecasts of peak-hour volumes were made by using as input data known service-level changes. For each site the forecast volumes are compared with the actual volumes for the after period, and a relative error or difference is computed and listed in Table 6. Also given in Table 6 are the average relative errors across all sites for the three modes. It is readily apparent that average errors and standard deviations are quite small for both the nonpriority automobile and the HOV bus modes. The largest errors occurred for the priority-granted carpool mode (-7.7 percent). Of course, more reliable forecasts are to be expected, because the model coefficients were estimated by using the same before-and-after data used in forecasting. Even so, the model is able to capture other effects in addition to shifts between modes. Clearly, this is a decided advantage compared with mode-choice (or general-share) models, given the importance of time-of-day and route diversion impacts. [See the report by Charles River Associates (3) for a comparison of the abilities of a pivot-point logit model to predict travel volumes for HOV facilities.]

In order to test the demand, supply, and equilibration components of the HOV worksheets, forecasts were also made by using only before data for each HOV site. (The one exception was to use the number of buses after the change in HOV facility for the San Bernardino, phase 1, site.) The forecasts and relative percentage errors are given in Table 7. The average errors increased slightly for the nonpriority automobile and priority bus modes but by a somewhat larger amount for the priority automobile mode.

The relatively higher standard deviations for the priority automobile or carpool forecasts indicate that other factors (either measurable, site-specific, or unobservable) in addition to those included in the model may influence the volume of carpools on the HOV facility. A lack of information describing the before-and-after characteristics of alternative highways in the HOV corridor prohibited a systematic examination of these effects within the context of this study. The tests reported earlier, however, clearly illustrate that the HOV models and worksheets can be used to provide a quick and reasonable examination of travel flows due to implementing alternative HOV strategies on freeways.

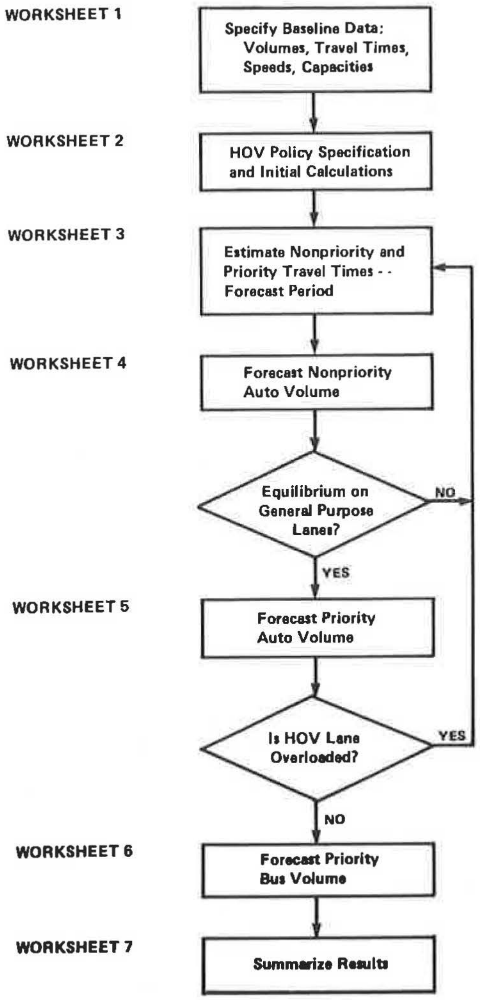

FIGURE 1 Activities undertaken in each worksheet.

EPILOGUE

All the existing HOV sites that were used in developing the relationships embedded in the forecasting approach share some common characteristics that help define the type of HOV treatments that can best be analyzed with the procedures presented here. First, the HOV lanes operate on (or adjacent to) major radial freeways leading into a central city or central business district. Thus, the proposed HOV corridor or lane should have similar characteristics (i.e., the approach may not yield reliable results

TABLE 6 Comparison of HOV Worksheet Predictions to Actual Travel Volumes: Actual Level-of-Service Changes Used

	Nonpriority Automobile Volumes				Priority Automobile Volumes				HOV Bus Ridership			
	Actual		Predicted	Relative Error[a]	Actual		Predicted	Relative Error[b]	Actual		Predicted	Relative Error[c]
HOV Facility	Before	After	After	[(P - A)/A]	Before	After	After	[(P - A)/A]	Before	After	After	[(P - A)/A]
Shirley Highway	4,896	5,126	5,105	-0.4	195	758	652	-13.9	7,900	8,756	8,595	-1.8
San Bernardino												
Phase 1	7,300	7,300	7,221	-1.1	NPA	NPA	NPA	–	402	1,017	1,018	+0.1
Phase 2	7,067	7,277	7,394	+1.6	299	576	761	+32.1	2,490	2,708	2,807	+3.7
US-101												
Phase 1	5,314	5,330	5,533	+3.8	NPA	NPA	NPA	–	3,370	3,572	3,748	+4.9
Phase 2	5,125	5,333	5,399	+1.2	205	288	289	+0.4	3,572	3,686	4,257	+15.5
Banfield Freeway												
Phase 1	3,713	3,845	3,790	-1.4	37	180	37	-79.4	340	570	407	-28.6
Phase 2	3,161	3,793	3,659	-3.5	708	1,180	846	-28.3	628	657	685	+4.3
I-95, Miami												
Phase 1	6,145	6,416	6,332	-1.3	170	309	321	+4.0	274	314	318	+1.3
Phase 2	5,170	5,880	5,919	+0.7	1,555	1,603	2,013	+25.6	314	352	335	-4.7
Southeast Expressway												
1977	5,504	4,306	4,269	-0.8	388	641	629	-1.9	2,000	2,124	2,205	+3.8
1971	4,554	4,201	4,226	+0.6	NPA	NPA	NPA	–	2,152	2,454	3,188	+29.9
I-495, Lincoln Tunnel	2,324	3,227	3,234	+0.2	NPA	NPA	NPA	–	21,868	26,092	26,254	+0.6

Note: NPA = no priority automobiles included in HOV treatment, A = actual, P = predicted. Data are from Charles River Associates.

[a] Average error = -0.03 percent, SD = 1.8 percent.
[b] Average error = -7.7 percent, SD = 34.9 percent.
[c] Average error = 2.4 percent, SD = 13.4 percent.

TABLE 7 Comparison of HOV Worksheet Predictions to Actual Travel Volumes: Only Before Data Used

	Nonpriority Automobile Volumes				Priority Automobile Volumes				HOV Bus Ridership			
	Actual		Predicted	Relative Error[a]	Actual		Predicted	Relative Error[b]	Actual		Predicted	Relative Error[c]
HOV Facility	Before	After	After	[(P - A)/A]	Before	After	After	[(P - A)/A]	Before	After	After	[(P - A)/A]
Shirley Highway	4,896	5,126	5,045	-1.6	195	758	654	-13.7	7,900	8,756	8,550	-2.4
San Bernardino												
Phase 1	7,300	7,300	7,195	-1.4	NPA	NPA	NPA	–	402	1,017	1,024	+0.7
Phase 2	7,067	7,277	7,415	+1.9	299	576	680	+18.0	2,490	2,708	2,846	+5.1
US-101												
Phase 1	5,314	5,330	5,512	+3.4	NPA	NPA	NPA	–	3,370	3,572	3,780	+5.8
Phase 2	5,125	5,333	5,438	+1.9	205	288	289	+0.3	3,572	3,686	4,258	+15.5
Banfield Freeway												
Phase 1	3,713	3,845	3,822	-0.6	37	180	46	-74.4	340	570	490	-14.0
Phase 2	3,161	3,793	3,662	-3.5	708	1,180	846	-28.3	628	657	685	+4.3
I-95, Miami												
Phase 1	6,145	6,416	6,864	+7.0	170	309	259	-16.2	274	314	325	+3.5
Phase 2	5,170	5,880[d]	6,347	+7.9	1,555	1,603	1,500[e]	–	314	352	335	-4.8
Southeast Expressway												
1977	5,504	4,306	3,909	-9.2	388	641	737	+15.0	2,000	2,124	2,124	0.0
1971	4,554	4,201	4,384	+4.4	NPA	NPA	NPA	–	2,152	2,454	3,170	+29.2
I-495, Lincoln Tunnel	2,324	3,227	3,253	+0.8	NPA	NPA	NPA	–	21,868	26,092	26,561	+1.8

Note: NPA = no priority automobiles included in HOV treatment, A = actual, P = predicted. Data are from Charles River Associates.

[a] Average error = -0.9 percent, SD = 4.7 percent.

[b] Average error = -13.9 percent, SD = 31.3 percent.

[c] Average error = 3.7 percent, SD = 10.6 percent.

[d] High violation rate.

[e] Model predicts saturated HOV-lane conditions.

for HOV lanes on surface arterials or HOV lanes on circumferential freeways). Second, the HOV lanes ranged from 2.5 to 9 miles in length. Third, all sites experienced force-flow or severe capacity constraint conditions on the general-purpose lanes in the before period during the morning peak hour. It appears, however, that the benefits would be slight (or even negative) if an HOV lane were instituted in a corridor that operated under relatively free-flow conditions during the morning peak hour.

Finally, among the HOV sites used in model estimation, many network conditions and alternative links (e.g., parallel freeways or arterials) exist, allowing different route diversion effects. The models and relationships that were developed reflect the average of these conditions. If a corridor being analyzed is especially atypical with respect to alternative routes, the models may not capture the full effects due to these alternative or competing links.

CONCLUSIONS

The development of a set of models for use in forecasting travel volumes resulting from implementing HOV strategies on freeways has been described. The models have been incorporated in worksheets that are described elsewhere (5).

To examine how well the models forecast, the procedures developed were used with known level-of-service changes to predict after peak-hour volumes of nonpriority automobiles, priority automobiles, and HOV bus passengers for each HOV site. More realistic tests were then made by using information only from the before period for each HOV facility.

Using known level-of-service changes, average relative errors were quite small for the nonpriority automobile (-0.03 percent) and HOV bus modes (+2.4 percent). The average error for the priority automobile mode was higher, although still quite acceptable (-7.7 percent). Using only the before data, average errors across the HOV sites increased slightly for the nonpriority automobile (+0.9 percent) and HOV bus (+3.7 percent) modes and by a somewhat larger amount for the priority automobile mode (-13.9 percent). In summary, these results demonstrate that the HOV models and procedures developed provide an effective way to estimate travel volumes that may result from implementing alternative HOV strategies on major freeways leading into the central area of cities.

ACKNOWLEDGMENT

The work described in this paper was performed by Charles River Associates under contract to FHWA. The author wishes to thank Howard Bissell, who, as contract manager, provided technical guidance during the course of the project.

The computer work was performed by Robert Hirschey, with econometric assistance provided by Lawrence Kolbe. Joan Solomon was involved in the initial data collection tasks. Useful supervision and direction were provided by Daniel Brand, with earlier assistance provided by William Tye and Fred Dunbar. Adolf D. May of the University of California at Berkeley contributed important input at various points throughout the course of this study. Finally, the author would like to thank the many individuals and agencies who cooperated with his requests for information on HOV evaluations.

Discussion

Olga J. Pendleton*

The objective of this discussion is to point out certain potential problems in least-squares regression analysis that could affect conclusions and resulting models. Whereas the author may have been aware of these problems and taken them into con-

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sideration, I feel it would be constructive to discuss this issue because it may be instructive for others engaged in similar model building.

In applying least-squares regression techniques to a set of data, it is important that the necessary distributional assumptions on the model errors be validated; these assumptions are that the dependent variable in the model, for example, change in traffic volume and be normally distributed and that the errors be independent and have homogeneous variances. This frequently is not the case when the random variable is a ratio of count data. In this instance, the error variance often increases as the ratio increases. Transformations of the variable such as the log transformation can often be used to accommodate the nonhomogeneous error problem. In this study the author uses weighted least squares with the weights being the square root of the sum of the total traffic volume. Weighted regression is another means of achieving variance homogeneity because the weights will be inversely proportional to the variance of the dependent variable and hence stabilize the variance. The weight used in this study, the square root of the traffic volume, thus implies that the variance of the change in traffic volume is inversely proportional to traffic volume. It is not obvious that as the traffic volume increases, the variance in the change in traffic volume decreases. It would be of interest to know why the author believed that this relationship exists.

Given the impact of the distributional assumptions on the model development and subsequent conclusions, the residuals from such a model (errors) should be examined to verify that they do indeed satisfy these assumptions. Examination of the cumulative distribution of these residuals and plots of the residuals versus model variables is an effective means of doing this. In fact, the examination of residuals by using unweighted ordinary least squares can sometimes lead to the selection of the appropriate weighting factor, which may be the method the author used to determine the weight in this study. This type of information would be extremely useful and enlightening to the reader.

There is a potential problem in the definition of some of the independent variables in this study, which could affect the results. Because this method of defining variables is fairly common, I would like to take this opportunity to explain the potential consequences of this practice by using two of the variables from this study in a hypothetical example. Consider the definition of the variable percentage change in travel time for two-person priority automobiles (PA2-TT). This variable was assigned the value zero for sites where two-person priority automobiles were not allowed onto the HOV lanes and took on the percentage values for all other sites.

Figure 2 might represent the relationship between PA2-TT and percentage change in traffic volume. The slope of the line using this method of defining PA2-TT would be strongly positive due to the number of low-volume change sites that did not allow two-person priority automobiles. If separate lines were fit to the sites that allowed two-person priority automobiles, the slope would be lower. One can easily construct other situations where including the zero PA2-TT sites in the analysis in this way could affect the resulting model coefficients. A method that would circumvent this problem would be to include an indicator variable that assigned the sites that allowed two-person priority automobiles a separate slope and intercept from those sites that did not. This indicator variable would take on the value 1 or 0 and its coefficient would correspond to the intercept of a line fit to those sites allowing those vehicle types only. Correspondingly, the coefficient for PA2-TT would take on a new interpretation, for example, the slope of a line for those sites only. Furthermore, the difference in average percentage volume change for the two groups of sites would be reflected in the test of significance of the coefficient of the indicator variable.

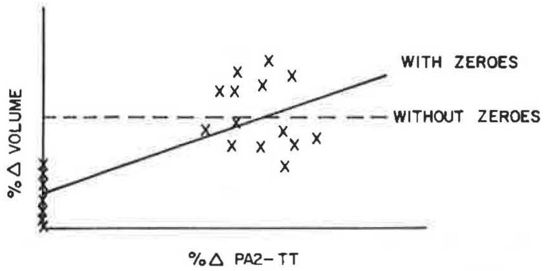

FIGURE 2 Relationship between PA2-TT and percentage change in traffic volume (Pendleton).

In reporting results from a regression model, information such as sample size and mean squared error (MSE) are as critical in model evaluation as R^2 or the F- and t-statistics. The latter statistics are difficult to interpret if the sample size is not reported. Whereas R^2 represents the percentage of the total variability in the data accounted for by the model, it can be unrealistically inflated for low sample sizes relative to the number of model parameters being fit. It also does not reflect the predictive ability of the model. The statistic that does this is the MSE, which is used in the computation of prediction and confidence intervals. If these prediction intervals had been reported in Table 6, they would have been useful in evaluating the predictive potential of the model. That is, if the predicted after volume for Shirley Highway is 5,105 ± 2,000, this would not be a good predictive model; however, if the model predicted within an interval of ±2, it would be extremely good. The author notes the danger in predicting the after volume by using the actual before volumes in the prediction. Why not report the predicted value of the expected percentage of change in total volume, that is, the dependent variable used to build the model, as well?

Table 5 gives results for several models, two of which do not appear to yield significant overall F-ratios. These values may be significant, but the reader is unable to verify this without knowing the sample sizes. An R^2 of 0.28 is surely too small to suggest any validity in the interpretations of these model parameters. Attempting to interpret signs and magnitudes of coefficients in such a model is like trying to make sense of random fluctuations about zero. If the overall F-ratio is not significant, this means that none of the model coefficients, tested simultaneously, are different from zero. To subsequently interpret the less sensitive t-statistics that test individually that each coefficient is different from zero corresponds to the error of interpreting some multiple range tests in a one-way analysis of variance when the overall F-ratio is not significant. As a point of clarification, in Table 5 why is the constant term omitted in models A and B? Omission of the constant term can have serious effects on the model fit and interpretation; thus it is important that there be evidence to justify its omission.

In conclusion, the problems addressed in this discussion could affect the conclusions based on least-squares regression analysis models. Because many of the points raised in this study are frequently overlooked by researchers using this method, the objective of this discussion was to enlighten researchers about these potential problems. The author of this study may well have taken these points into consideration in this analysis. However, because many of these points are frequently ignored by the researcher, it would be beneficial if studies such as this one addressed these points in the literature.

Author's Closure

The discussion by Pendleton highlights various generic issues that one should be aware of in using least-squares regression analysis in model-building exercises. I share her concern that these issues may not always be properly examined by those using available regression packages, and I believe that her discussion and this response can provide useful information to others.

WEIGHTED LEAST SQUARES

As described by Pendleton, weighted least squares is used to correct for heteroscedasticity in order that efficient parameter estimates and unbiased estimates of the variances are obtained. Typically, prior information is not available to obtain estimates of the variances of the individual error terms in order to determine the appropriate weights. However, if it is suspected that the error variances are proportional to the size of an independent variable, for example, then a set of weights can be constructed. In this particular instance, the objective was to develop models to forecast after modal volumes as a function of before vehicle volumes and changes in levels of service (principally travel times for the own and competing modes). We also suspected that the variances in peak-hour volumes would decrease as travel volumes increased. In this instance the appropriate procedure was to weight the dependent and independent variables by the square root of the volumes. Subsequently, the dependent variable was redefined to be the percentage change in modal volume, but the weights were left unchanged. In effect, this presumes that the variances in the change in travel volume decrease as volume increases. To check this assumption, the priority automobile model in Table 4 was reestimated, first assuming that variances are inversely proportional to what was originally used and second that variances are constant, such that weighting is not necessary.

The results of the initial and two additional cases described earlier were nearly identical. The mean square errors were 0.231, 0.231, and 0.226, respectively. Because weighting is a procedure used to obtain better estimates of the parameter variances, the estimated values of the model coefficients were nearly identical for the three alternatives. We thus conclude that it is probably not necessary to use weights when ratios of travel volumes are used as the dependent variable but doing so did little to affect the model parameters and statistics.

DEFINITION OF VARIABLES

Pendleton discusses how alternative procedures for describing a variable (in this instance, PA2-TT) may affect the estimated value of the parameter. In general, it is likely that different variable definitions will produce different model results; the same is also true for different functional forms (e.g., linear versus log transformations). With respect to the latter point, alternative functional forms were evaluated and, as reported in the paper, the model form as described by Equation 1 was selected. With regard to the variable PA2-TT (the percentage change in travel time when two-person vehicles were allowed to use the HOV facility), different definitions were also examined, including ones essentially similar to those described by Pendleton.

Basically, given the limited sample size (because of the relatively low number of localities in the United States where two-person carpools were allowed onto a freeway HOV facility and adequate volume and level-of-service data were collected), we could not detect a consistent pattern between changes in travel times for vehicles on the nonpriority lanes (NPA-TT) and percentage change in priority automobile volumes. Consequently, if the variable PA2-TT was assigned the same value as NPA-TT when buses or carpools of three or more were allowed onto the HOV facility but took on the actual percentage change in travel time when carpools of two or more were allowed onto the HOV lanes, the significance of the parameter was greatly diminished because there are more of the former sites. Thus, the variables PA2-TT and PA3/4-TT (one or the other but not both) contribute information to the right-hand side of the equation if they have something of significance to explain (in that either two- or three-or-four-or-more-person carpools save time because of the introduction of the HOV strategy).

Although Figure 2 graphically demonstrates how one might view the consequences of restricting certain values to zero, it cannot be used in this instance to infer how the slope and the intercept may change. The reason is that in some instances, the percentage change in volume of two-person carpools may be negative if carpools of three or more persons are allowed on the HOV facility, or vice versa. This would be graphically depicted as shown in Figure 3.

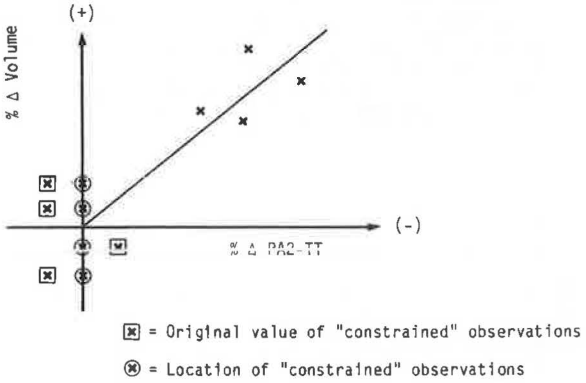

FIGURE 3 Relationship between PA2-TT and percentage change in traffic volume (Parody).

REGRESSION STATISTICS

I agree with Pendleton's remark with respect to reporting a full range of statistics from the model estimation process. It is a shortcoming I too have lamented in the work of others.

When weights were used in generalized least squares, the MSEs reported in the estimation package being used described characteristics of the newly transformed data and therefore did not provide correct information for the original data. Thus, they were not reported in the first draft of the paper. However, the MSEs for the unweighted data have now been calculated and, along with the degrees of freedom (DFE) (which equal the sample size less the number of variables in the model), are included in the tables. A note on their interpretation and application might be useful, however. The MSE values apply to the dependent variable (i.e., percentage change in a particular modal volume). A certain amount of mathematics is required to transform that statistic to the ultimate variable of interest, modal volumes after the introduction of the HOV facility.

The standard error of the estimate [i.e., the standard deviation ($\bar{\sigma}$) of the variable on the left-hand side] is equal to the square root of the MSE. Therefore, for the Shirley Highway example mentioned by Pendleton, the estimated percentage of change in volume for nonpriority automobiles ($\hat{PVNPA}$) can be calculated (using Tables 1 and 3) as follows:

$$\begin{aligned}\hat{PVNPA} = & -0.916 - 1.053[(58.3/56.2) - 1] \\ & + 1.190\ [(58.3/56.2) - 1] \\ & + 0.122\ [(38.3/56.2) - 1] \\ & + 0.278\ [(38.3/37.5) - 1] \\ & + 0.949\ \{(3/3) \cdot [(4{,}896 \\ & + 195 + 0)/4{,}896]\}\end{aligned}$$

$$\hat{PVNPA} = 0.043 \tag{4}$$

Given that the formula for computing the after volume of nonpriority automobiles ($VNPA_1$) is

$$VNPA_1 = VNPA_0(1 + PVNPA) \tag{5}$$

then

$$VNPA_1 = 4{,}896(1 + 0.043) = 5{,}105 \text{ vehicles per hour} \tag{6}$$

The confidence interval for the forecast volume of 5,105 vehicles per hour on the nonpriority lanes of Shirley Highway is equal to the following expression:

$$\hat{VNPA}_1 = VNPA_0[1 + (PVNPA \pm t_{\alpha/2}\sqrt{h_i S^2})] \tag{7}$$

where

S^2 = MSE = 0.0007,
h_i = the leverage = $x_i(X'X)^{-1}x_i'$, and
$t_{\alpha/2}$ = 2.45 for 95 percent confidence interval and 6 DOF.

Because the value of h is not readily available, it is set equal to 1 (which equals its value when intervals are constructed around the mean of the independent variables) such that the confidence interval of the forecast for Shirley Highway is approximately as follows:

$$\hat{VNPA}_1 = 5{,}105 \pm 317 \text{ vehicles per hour} \tag{8}$$

Pendleton suggests reporting the predicted values of the percentage change in travel volumes. Although such a list would be useful in evaluating alternative models, it could tend to obscure what is happening on the highway. For example, the actual percentage increase in three-person automobiles for the San Bernardino, phase 2, case is 92 percent, whereas the priority automobile model forecasts an increase of 154 percent. Expressed in terms of vehicle volume, this difference amounts to only 185 vehicles per hour (see Table 6). The reader, however, can easily calculate both the actual and forecasted percentages from Tables 6 and 7.

Pendleton is correct in stating that one or two of the priority bus models are not highly significant. As described in the text, likely reasons relate both to the unavailability of information on fares, frequencies, availability of park-and-ride facilities, and route coverage and to the desire to produce a sketch-planning procedure using available data that can provide forecasts from beginning to end in one day or less. However, it is interesting to note that the after bus passenger volumes predicted by the models in Table 5 differed from actual volumes by an average absolute amount of 13.4 percent (see Table 6).

In Table 5 both models A and B were originally estimated with a constant term. In the case of model A, the inclusion of a constant reduced what little significance there was for the variable PTB to zero. Thus, the choice was between a model that would produce the same change in bus volumes irrespective of the change in bus level of service (i.e., even if there was no change in bus travel time), and one that was at least partially sensitive to alternative HOV configurations and local site conditions. Given that we expect the intercept to be basically zero when PTB is zero, the latter model was chosen. (With only one variable, tests of the F- and t-statistics produce the same results, which Pendleton could not ascertain without knowing whether or not a constant had been used.)

In the case of model B, the constant was estimated to have a value of zero. Because of the high explanatory power exhibited by the supply variable (percentage change in number of buses), likely because of its being highly correlated with bus ridership, there was not much left to be explained by a constant term.

In summary, the models presented in the paper quantitatively relate changes in volumes to changes in service levels for a dozen HOV facilities across the United States. The models were formulated to be consistent with the task of using actual before-and-after data to develop a set of forecasting procedures that could be used to examine changes in modal volumes for alternative HOV strategies in a quick-response time frame. As more data for these types of TSM options become available, the models may be refined. Revised model coefficients can easily be substituted in the worksheets presented in the User's Guide (5), and sensitivity tests can be performed.

I hope that the observations made by Pendleton relating to model estimation and the subsequent discussion on how they were addressed in the study are illuminating and will assist others when conducting and reporting on least-squares regression analysis models.

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