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Priority Lanes on Urban Radial Freeways: An Economic-Simulation Model

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A simulation of the effects of opening a priority lane on a commuter-oriented freeway is carried out by combining a simple deterministic queuing model of traffic flow with a disaggregate model of modal choice. This permits iterative determination of a supply-demand equilibrium and a precise definition of the resulting benefits within the framework of cost-benefit analysis. By varying the assumptions parametrically, illustrative results for a wide variety of cases are obtained. The benefits are substantial for those cases where initial congestion is heavy. The combination of the rigorously derived objective function and the model of modal choice constitutes a proposed methodology for analyzing highway management policies that could be adapted for use in more detailed engineering studies of particular facilities. The results given here, although derived from a highly simplified model of traffic flow over a peak period, suggest the results that can be expected from such applications.

Our understanding of priority-lane operations and car-pooling behavior has grown rapidly in recent years because of the urgent need for public-policy guidelines. Sophisticated traffic-flow models (10, 13, 14) now permit detailed investigation of patterns of traffic flow under various circumstances. A flurry of activity among demand modelers has produced a number of disaggregate modal-choice models that predict the response of voluntary car pooling to various incentives (Ben-Akiva and Atherton, in a paper in this Record).

Each of these sides of the analysis depends on the other: Traffic-flow models make predictions that are contingent on the volume and mix of traffic, and forecasts from demand models must take as given the costs and levels of service encountered by the users of each mode. The use of either procedure alone may be valid only within an unknown and possibly narrow range of conditions.

Therefore, the need is for an integrated model that determines levels of service and levels of demand simultaneously. Such a model consists conceptually of nothing more than that most basic tool of microeconomic analysis, the supply-demand equilibrium. The demand side is provided by the demand-forecasting model, which predicts the quantities of various types of highway services that individuals will choose, given their prices in terms of monetary cost and level of service. The traffic-flow model and the cost information determine the price that must be paid by users to obtain a certain volume of peak-hour highway services and thus constitute the supply side of the equilibrium.

This paper describes such a model and demonstrates its usefulness by analyzing the impact of a priority lane on an idealized radial freeway subject to peak-period congestion by commuters. The model and results are described more fully by Small (12).

A secondary purpose is to show that the incorporation of a disaggregate demand model facilitates a clear and theoretically rigorous definition of user benefits that is consistent with accepted principles of cost-benefit analysis and to calculate these benefits for the policies considered to form some generalizations about the desirability of priority lanes as public policy.

The model focuses on the supply of and demand for the services of a section of radial freeway during the morning and afternoon peak commuting periods. Congestion is explicitly modeled only on the freeway section itself. All characteristics of the access and distribution networks are assumed to remain constant and enter the model as determinants of demand for the freeway study section.

SUPPLY MODEL

The idealized highway section to be considered is a 10-km (6-mile) length of freeway with no entrance or exit ramps that is used only by commuters. All access to this line-haul section is at one end and all egress is at the other, with the direction reversing from morning to evening. The collection of commuters at the access end and their distribution at the egress end take place on a variety of roads that may include extensions of the study section. [Access and egress are described in a disaggregate manner in the next section of the paper; this section describes traffic flow and cost assumptions for the 10-km (6-mile) section itself.]

Traffic flow on this line-haul section is described by assuming a uniform speed of S_0 km/h ($0.62S_0$ mph), except for the delay caused by deterministic queuing behind a a single bottleneck of capacity C vehicles/h. That is, if t_1 is the time of day at which traffic volume [D(t)] entering the freeway first exceeds C, then travel time (T) (in minutes) over the section for a vehicle entering at a later time t, providing the queue does not dissipate prior to t, is

$$T(t) = (600/S_0) + (60/C) \int_{t_1}^{t} [D(t') - C]\, dt \qquad (1)$$

In terms of queuing theory, the integral gives the queue length in vehicles, and (60/C) is the service time in minutes.

This model has been used by May and Keller (9) to analyze the San Francisco-Oakland Bay Bridge. To apply it to the typical radial freeway may seem a bit more tenuous, but it duplicates remarkably well the actual travel times observed during the afternoon rush hour on an 18-km (11-mile) section of I-80 on the eastern side of San Francisco Bay. This study used the results of an origin-destination study to compute net demands at 15-min intervals for a particular three-lane subsection that appears to be the chief bottleneck (1, pp. 8 and B-2).

The parameters S_0 and C were adjusted by trial and error to obtain a satisfactory fit, which gave $S_0 = 89.7$ km/h (53.8 mph) and C = 1770 automobile-equivalents/h/lane. These values are retained for the present study, with a bus assumed to cause congestion equivalent to 1.6 automobiles (3, p. 257). The institution of a priority lane is assumed to result in two separate traffic streams, each governed by this type of queuing analysis.

The primary endogenous service-level variable is taken to be the average travel time ($\bar{T}$), in minutes, over a peak period of duration (W) with uniform demand volume (D). This may be easily calculated from Equation 1 to be

$$
\begin{aligned}
\bar{T} &= 6.7 \qquad (D \leqslant C) \\
&= 6.7 + [(D/C) - 1](60W/2) \qquad (D > C)
\end{aligned}
\tag{2}
$$

The assumption that commuters ignore variations in queuing delay over the peak period probably does not affect the results significantly, because in reality commuters tend to adjust their times of travel to minimize that variation. The assumption that the peak-period duration is fixed, however, is potentially important and will be discussed later. Also, the benefits of congestion-reducing policies will be somewhat underestimated because the effect on those individuals who arrive after the peak period but before the queue is dissipated is ignored.

The cost of providing automobile or bus service over the line-haul section are estimated as realistically as possible as a function of $\bar{T}$, by relying on methodology developed by Keeler and others (4) and Small (12). All costs are given in 1972 prices and therefore precede the rapid increases in gasoline and labor costs of the past 4 years.

Costs of automobile travel are assumed to include only the maintenance and operating costs for a compact automobile and to vary with average speed proportionally to fuel consumption. This gives a relation that shows costs per vehicle to be approximately constant at 2.3 cents/km (3.8 cents/mile) for freeway speeds between 67 and 100 km/h (41 and 62 mph), and to rise fairly rapidly outside that range. (This fuel-economy relation was measured under actual freeway conditions and hence reflects the increased congestion that causes lower average speeds.)

To adequately describe the changes in bus service resulting from changes in freeway speeds and aggregate ridership levels would require a model of bus operational policy that predicts route density, headway, and fare. Such models have been developed by assuming either some kind of social optimization (4) or a profit maximization subject to fixed fare (5), but it is not clear that either assumption characterizes actual bus agencies. Instead, it is assumed here that buses are added to existing routes in such a way that occupancy and waiting time remain constant, but that fares are adjusted for any cost changes due to changes in $\bar{T}$.

Studies of bus operations (4, 12) gave assumed agency costs of 11.5 cents/vehicle•km for maintenance and operation, \$15.52/vehicle•h for labor on peak-period runs, and \$5898/vehicle•year for capital cost. Each daily peak-period run was then assumed to require a 20-km (12-mile) round trip with a revenue-haul taking time of $\bar{T}$ and an empty back-haul taking time of 6 min. Adding 10 percent to these figures for miscellaneous extra running time, assuming a bus occupancy of 37, and distributing capital costs over 255 working d/year gives costs of ($13.18 + 1.056\bar{T}$) cents/one-way passenger trip.

In summary, the supply model predicts, for a given total passenger volume and modal split, the line-haul travel times and costs faced by automobile and bus commuters using a given section of freeway. To complete the picture requires a demand model that uses these times and costs to predict the modal volumes.

DEMAND MODEL

The demand for use of a section of radial freeway by commuters is modeled here as a problem of modal choice with a fixed number of total trips. The use of the disaggregate demand approach has two steps. The first is the specification and calibration on some survey sample of a behavioral modal-choice model. This will predict the probability that an individual with given observable socioeconomic characteristics and transportation opportunities will choose one of four modes: automobile noncar pool, car pool, bus with walk access, or bus with automobile access.

The second step is a description of the distribution of these socioeconomic characteristics and transportation opportunities among the population of commuters who use the freeway section in question; this is done by a forecasting sample believed to be representative of such commuters. This step is absolutely essential for unbiased forecasts from the disaggregate modal-split model (8); in the present context, it is here that the characteristics of access to and egress from the freeway study section are accounted for. Also, although in the present paper they are overlapping subsets of a common data base, the forecasting and calibration samples may be entirely distinct; the former must provide a representative selection of the underlying preferences of the population whose behavior is in question, whereas the latter must be representative of their socioeconomic and locational situations.

In this paper, both the calibration and forecasting samples are subsets of a sample of 213 commuters in the San Francisco Bay Area, who were surveyed in 1972 as part of the project reported by McFadden (7, pp. 315-319). The project staff combined the survey information with extensive highway and bus transit data to obtain a complete description of the sample individuals in terms of socioeconomic and transportation variables.

For the calibration sample, the full sample was narrowed to 161 by excluding individuals who walked or bicycled to work or who were captive automobile users because of regular use of the household automobile at work or no feasible bus service available. For the forecasting sample, on the other hand, the desire was to find a sample representative of the users of a typical 10-km (6-mile) length of radial freeway. Since it happened that the original sample of 213 was drawn primarily from potential users of major freeway routes, the present purposes were served simply by narrowing it to those whose trips, if taken by automobile, would involve a substantial length of freeway. There was no requirement that actual express bus service on the freeway be available to the individual; in the absence of such service the forecast uses existing local service as the basis for the assumed travel time and fare at which express service could be instituted. The resulting sample, after eliminating a few for whom no bus service of any kind existed, had 118 individuals.

Calibration of Behavioral Modal-Choice Model

The theory behind the behavioral model of modal choice used here is that the ith individual perceives a utility from a trip on the mth mode of

$$V_m^i = W_m(S^i, x_m^i) + \epsilon_m^i \tag{3}$$

where W_m are universal functions of the socioeconomic characteristics S^i and the transportation variables x_m^i, and where ϵ_m^i express the unobservable idiosyncratic tastes of individual i. McFadden (2, 6) has shown that, if ϵ_m^i is assumed to have a Weibull population distribution independent of m, then the probability that an individual will choose mode m, given his observable characteristics S^i and x_m^i, is given by the logit formula:

$$P_m^i = \exp(W_m^i) \Big/ \sum_n \exp(W_n^i) \qquad (4)$$

where $W_m^i = W_m(S^i, x_m^i)$. Given observations on S^i and x_m^i for a sample of individuals and on their actual modal choices, the maximum-likelihood procedure described by McFadden (6) may be used to estimate the parameters of the functions W_m.

The functional form of W_m must be specified in advance, which involves a number of complex issues (12, 15) whose resolution is only summarized here. Socioeconomic variables are included only insofar as there is a priori reason to believe that they serve primarily as indicators of tastes and are exogenous over a time span of several years. Costs are entered as a fraction of the marginal posttax wage rate, given by $w = w_0(1 - \tau)$, where w_0 is the actual wage rate and τ is the tax rate of the income tax bracket determined by the total income of the family. The model therefore implicitly estimates values of time as fractions of this wage. Separate travel-time components are distinguished insofar as the sample size and the quality of the data permit.

The car-pool mode is defined as participation (either as driver or passenger) in a trip by automobile containing three or more people. Rather than adding an arbitrary amount of time to the car-pool trip to account for the extra driving, loading, and unloading, a single car-pool dummy variable permits the calibration procedure itself to estimate an implicit time penalty, which includes both actual extra time and a penalty in time-equivalents for whatever other undesirable features, such as scheduling inconveniences and personal incompatibility, that car pooling may have.

The estimated coefficients are shown in Table 1. Their magnitudes and signs agree with intuition and with other results, except for the first-wait time, which has an excessively high value (469 percent of the marginal posttax wage rate) that is partly responsible for the decision not to incorporate headway changes into the supply model. On-vehicle time is valued at 54 percent of the wage and walk time at 83 percent. A transfer (including the time associated with it) is valued at 13.6 min of on-vehicle time, whereas the inconvenience of car pooling (relative to lower occupancy automobile) is, depending on age and the hours of work, as objectionable as 100 to 160 min of round-trip on-vehicle time!

Such a large natural barrier to car pooling should not be construed as evidence of the hopelessness of incentive policies; indeed, it may suggest the presence of important omitted determinants (e.g., advertising and computer matching services) that are subject to policy manipulation. Other variables tried as explanatory for the car-pool versus non-car-pool automobile choice, but found to give statistically insignificant coefficients, were income, children, length of residence in the neighborhood, and number of workers in the family.

Forecasting Aggregate Modal Split

Turning now to the second step in the construction of demand for the freeway study section, Table 2 shows the main features of the forecasting sample. A typical one-way trip by automobile is 28.4 km (17.5 miles) long and takes 31.5 min; by bus, the same trip takes 49 min of on-vehicle time, one transfer, and (for the morning trip) a 19-min initial headway. As expected from the relatively high incomes represented, this largely suburban sample generates modal-split forecasts that are heavily biased toward the automobile.

To forecast modal split as a function of line-haul times and costs for the various modes, the utilities (W_m^i) are first computed from Equation 5 for each forecasting sample member. The travel times and costs assigned to him or her in the forecasting sample are assumed to include (whatever the mode) the equivalent of a 10-km (6-mile) line-haul trip at 67 km/h (40 mph), the approximate average peak-hour speed observed on major Bay Area radial freeways in 1972. W_m^i is then modified for differences in the line-haul times and costs from this base condition, and the individual modal-choice probabilities are calculated from the logit equation 4. These probabilities are then averaged over the forecasting sample and adjusted to account for the captive automobile commuters, who were excluded from the calibration sample, to obtain aggregate modal-choice probabilities, which are now a function solely of the line-haul times and costs.

The resulting modal-split functions are fairly insensitive to line-haul times and costs. Under 1972 base conditions, 75 percent chose one of the automobile modes. Increasing one-way automobile times by 24 min reduces this to 65 percent; alternatively, the same reduction could be achieved by a one-way toll of $1/automobile.

EQUILIBRIUM RESULTS

The supply and demand models described in the previous sections were computerized, and an iterating algorithm was written to determine the equilibrium values of modal-split and line-haul times and costs for a given total passenger volume. Some results are given in Table 3 for three values of passenger volume, chosen to be representative of conditions that lead under base conditions (no priority lane) to moderate, heavy, and very heavy congestion (defined respectively as one-way delays of 6.8, 15.6, and 24.0 min).

Except at conditions of very heavy initial congestion, a bus-and-car-pool lane increases the queuing in the other lanes, in spite of a substantial decrease in traffic due to induced modal shift. A bus-only lane is, of course, even worse in this respect. To evaluate the effect of divisible lanes, the model was run with the assumption that the total capacity could be divided into any fraction desired, that fraction being set so as to just avoid queuing among priority vehicles. The results indicated that nonpriority queuing is much less severe and that ideally only 8 to 12 percent of total capacity should be allocated to priority vehicles.

BENEFITS

The claim that the incorporation of a behavioral demand model permits the definition and computation of rigorous measure of benefits is based on the theory of cost-benefit analysis, in which benefits are defined as the sum over all individuals of the amounts of money each would be willing to pay for the change plus the identifiable money flows to relevant parties, e.g., government tax collections.

To define the willingness of an individual to pay for a change in the transportation environment facing him or her, let V^{i*} represent the utility actually achieved by choosing the best mode. From Equation 3

$$V^{i*} = \max_m V_m^i = \max_m (W_m^i + \epsilon_m^i) \qquad (5)$$

It is assumed that the marginal utility of money (λ^i) is given by the coefficient of travel cost in the behavioral demand model, which is equal to the estimated coefficient divided by the individual's wage (w^i). The incremental willingness to pay for a change that alters the utilities (W^i_m) is then

$$dB^i = (1/\lambda^i)dV^{i*} = (1/\lambda^i)dW^i_k \qquad (6)$$

where k is the mode actually chosen.

Everything in Equation 6 except k is observable for an individual in the forecasting sample. The nature of this stochastic utility model is such that the mode an individual will choose cannot be predicted with certainty, and thus his or her benefits from changes that affect modes differentially cannot be predicted. However, for aggregate purposes, it is sufficient to know the expectation of benefits:

$$E[dB^i] = (1/\lambda^i)\sum_m P^i_m dW^i_m \qquad (7)$$

where P^i_m is given by the logit formula (Equation 4). Integration of Equation 7 gives the following index of direct benefits:

$$B^i = (1/\lambda^i)\ln\left[\sum_m \exp(W^i_m)\right] \qquad (8)$$

In the course of computing the modal-choice probabilities for each individual in the forecasting sample, it is simple to compute this benefit index and aggregate it over the sample. To this value, must be added the benefits accruing to captive automobile users, which are calculated directly from Equation 6 by assuming that the mode chosen is non-car-pool automobile. Finally, the changes in gasoline tax revenues are added to obtain the direct benefits given in Table 3.

This measure of social benefits is termed direct because it excludes a number of potentially quantifiable effects that are external to the present model, but that may be quite important for actual policy purposes. These include parking subsidies, subsidies to bus feeder routes, congestion costs outside the central business district, changes in bus headways or route densities, automobile capital and accident costs, and air pollution. Estimates of these indirect benefits (12, pp. 218-224) indicate that including them would greatly reinforce the case for any policy that reduces automobile traffic.

The results for the bus-and-car-pool lane in Table 3

Table 1. Modal-choice models: estimated coefficients.

Independent Variable (round trip)	Coefficient	Standard Error
Cost[a] ÷ marginal posttax wage, ¢/min	-0.0413	0.0116
On-vehicle time, min	-0.0224	0.0120
Walk time, min	-0.0343	0.0162
First-wait time, min	-0.1938	0.0600
Number of transfers	-0.3043	0.1982
Mode 3 dummy	-1.25	0.48
Automobile dummy[b]	-5.23	1.39
Family income[b], $000s (ceiling of 10)	0.310	0.112
Children under 18 living at home (dummy)[b]	-0.645	0.540
Length of residence in neighborhood[b], years	0.119	0.042
Respondent's age ≥ 45 (dummy)[b]	-0.660	0.574
Car-pool dummy[c]	-2.44	0.54
Respondent's age ≥ 45 (dummy)[c]	-1.138	0.691
Respondent works standard hours (dummy)[c,d]	0.098	0.302
Likelihood ratio index[e]	0.448	—
Percentage correctly predicted[f]	71.4	—

Notes: Sample size = 161.
Mode 1 = automobile with < 3 occupants; mode 2 = bus with walk access; mode 3 = bus with automobile access; mode 4 = car pool with ≥ 3 occupants.

[a] Cost for the automobile modes consists of maintenance and operating costs [at 3.3¢/km (5.3¢/mile)] plus tolls and parking, all multiplied by an expected share of 1/1.11 for mode 1 or 1/3.52 for mode 4.

[b] The variable is as described on modes 1 and 4, zero on other modes.

[c] The variable is as described on mode 4, zero on other modes.

[d] If official work start time is 7:45 to 9:15 a.m. and quit time is 4:15 to 5:45 p.m., this variable is 2. If one of the above holds, it is 1. If neither holds or there are no official times, it is 0.

[e] The likelihood ratio index is the percentage increase in the log likelihood when maximized over its value with all coefficients 0.

[f] A case is correctly predicted if the mode actually chosen is the one with the highest predicted probability.

Table 2. Forecasting-sample summary statistics.

Variable	Mean	Standard Deviation
Automobile round trip		
Distance, km	58	20
On-vehicle time, min	63	26
Parking cost, ¢/vehicle/d		
All trips	41	77
Excluding free parkers	134	84
Bus round trip		
On-vehicle time, min	98	30
Walk time, min	28	19
Number of transfers	2.1	1.4
Fare, ¢	142	64
Other		
First bus headway home to work, min	19	16
Family income, $000s/year	14.8	7.0
Marginal posttax wage, $/h	4.21	1.94

Note: 1 km = 0.62 mile.

Table 3. Equilibrium results.

Policy	Total Passenger Volume per Hour per Lane	Fraction of Total Capacity Used for Priority Lane	One-Way Queuing Delay (min)		Modal Split (%)			Priority Lane Capacity Use (%)	Direct Benefits Relative to Base Case (¢/passenger/d)
			Automobile	Bus	Automobile Noncar Pool	Automobile Car Pool	Bus		
Base case: no priority									
Moderate congestion	3160	0.33	6.8	6.8	65	10	25	—	—
Heavy congestion	3580	0.33	15.6	15.6	64	11	25	—	—
Very heavy congestion	4000	0.33	24.0	24.0	64	12	24	—	—
Bus priority									
Moderate congestion	3160	0.33	20.0	0.0	53	8	39	9	-65
Heavy congestion	3580	0.33	25.2	0.0	50	7	43	11	-13
Very heavy congestion	4000	0.33	29.7	0.0	47	7	46	14	43
Bus and car-pool priority									
Moderate congestion	3160	0.33	15.6	0.0	52	14	34	29	-28
Heavy congestion	3580	0.33	19.8	0.0	49	16	36	36	32
Very heavy congestion	4000	0.33	23.7	0.0	46	17	37	44	94
Bus and car-pool priority; divisible lanes									
Moderate congestion	3160	0.08	4.3	0.0	62	11	28	100	37
Heavy congestion	3580	0.10	9.4	0.0	57	12	30	100	89
Very heavy congestion	4000	0.12	14.2	0.0	53	14	33	100	143

range from direct benefits of -28 to +94 cents/commuter/d, depending on the degree of initial congestion. The benefits could be much greater, though the induced modal shift would be smaller, if lanes were perfectly divisible, so as to eliminate the waste of capacity in the underused priority lane. There is a large potential payoff for the development of methods to allow a priority queue to bypass without using an entire lane, and substantially more engineering effort should be devoted to this aspect of the problem. Some tentative suggestions have been made by Small (12, pp. 76-82).

It must not be thought, however, that either full use of the priority lane or an absence of increased queuing is a prerequisite for positive benefits from a priority-lane operation. For example, under initially heavy congestion, a bus-and-car-pool lane carries traffic equal to only 36 percent of its assumed bottleneck capacity and increases the one-way queuing delay for nonpriority vehicles by 4.2 min, yet the direct benefits are positive. This is because the queuing delays are reassigned to different vehicles in an economically efficient manner: Those vehicles whose occupants in aggregate possess a higher value of time (per unit of road capacity used) are permitted to go faster at the expense of others because the benefits to the former outweigh the disbenefits to the latter in the impersonal scales of cost-benefit analysis.

SOME PERSPECTIVES ON RESULTS

Several points may be made in interpreting the usefulness of the model and results presented here.

First, are the potential benefits from priority lanes large? Consider the case of a bus-and-car-pool lane for a six-lane facility initially subjected to heavy congestion. If 255 working d/year are assumed, the estimated direct benefits of 32 cents/passenger/d equal \$1.75 million/year. Compared to the total round-trip costs of commuting, benefits of 32 cents/passenger would appear to be significant, although far from overwhelming. Compared to implementation costs, \$1.75 million/year appears very large. The Voorhees and Associates study (16, p. 25) estimated signing costs for a 19-km (12-mile) priority lane on each side of the I-90 Memorial Shoreway in Cleveland at \$235 000 capital expenses plus annual maintenance and operating costs of \$14 000. Even if special entrance ramps of the type built for a contraflow lane on I-495 in New Jersey (11, p. 23) are added on each side, the capital costs are only about \$500 000. If this is annualized liberally with a capital-recovery factor at a 10 percent interest rate and a 15-year lifetime, the total annual costs are \$80 000, which is an order of magnitude below the potential benefits.

Second, the present model understates the benefits of reducing automobile traffic. Furthermore, the conventional priority lane analyzed here is not necessarily the most favorable configuration for all situations. Other alternatives include contraflow lanes, extra lanes in a median strip, and priority metering at entrance ramps. All of these require greater initial expense, but they may provide considerably greater benefits because they cause less disruption to nonpriority flow. With some modification, the model could be applied to the analysis of such policies.

Another alternative is congestion pricing, in which a peak-period toll, equal to the marginal cost that each vehicle inflicts on all other users through increasing congestion, is charged. In the present model, this marginal cost is the value of the additional travel time and running cost imposed by a user on all those behind him or her in the queue. This alternative was analyzed by using the model and had benefits that exceeded those of a priority lane by about \$1/passenger/d. For the heavy-congestion case, a round-trip toll of \$2.22/automobile eliminated queuing delays entirely and resulted in increases of 13 and 1.5 percent in bus and car-pooling frequencies respectively.

Finally, the effects of some of the simplifying assumptions of the model should be explored. First, the neglect of the speed versus flow relation on those parts of the freeway not affected by queuing appears to affect the results very little, because the overall travel time is much more sensitive to queuing than to nonsaturated speed reductions. Second, the model overstates the changes in congestion levels during the peak period by not allowing for alternative routes and times of day. Third, by excluding nonwork travel, the model probably overstates the modal shifts induced.

CONCLUSIONS

This paper is in large part intended as a contribution to the development of methodologies for evaluating urban-highway operating policies. It appears both desirable and feasible to analyze such policies in an equilibrium context, in which the interaction between traffic-flow relations and demand characteristics is explicitly recognized and in which the benefits to individuals can be defined and evaluated in a rigorous way. The particular model described here is one way to approach this goal, and the results suggest what may be expected from more detailed applications. Either the supply or demand sides of the model can be made more complex and case specific.

Other limitations of the model can be removed only with greater difficulty. To incorporate nonwork trips would require more complex demand modeling. To eliminate the assumption of a fixed-duration peak period would require some behavioral description of individual decisions on the timing of their trips. Finally, the assumption of a fixed number and location of commuters prohibits consideration of the longer range effects of various policies on the shape of an urban area. The further development of the present model on these lines would be both challenging and rewarding.

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Choice-Model Predictions of Car-Pool Demand: Methods and Results

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The results of a number of car-pool strategies were predicted by using disaggregate choice models. Car pooling is explicitly considered as an alternative mode only for work trips. However, the effects of car-pooling incentives on interdependent travel choices and vice versa are also predicted. Forecasts are made by applying the models to each household individually, using revised values of the appropriate independent variables to simulate the particular transportation alternative being analyzed. These household predictions are then summed to represent predicted areawide changes in travel behavior. Before and after data from the implementation of car-pooling incentives and transit-service improvements were used to test the validity of the model's forecasts. Three such tests are reported. The results indicate that the work-trip modal-choice model successfully captures the effects of changes in level of service on modal choice. The predicted effects of several significant car-pooling strategies are presented. In general, traveler response to many car-pooling incentives is small. The most significant changes in travel behavior are predicted for those parking-related policies that combine disincentives for driving alone with incentives for car pooling.

Various strategies designed to increase ride sharing have been proposed and several have already been implemented. For example, strategies such as preferential lanes for high-occupancy vehicles, car-pool-matching and promotion programs (both areawide and employer-based), and preferential parking for car pools have existed for several years. This paper applies a methodology based on disaggregate travel-demand models to predictions of changes in travel patterns that will result from car-pooling incentives and from short-range transportation options in general.

The methodology is described briefly, and a number of validation tests that use before-and-after data are presented. Prediction results from case study applications of the methodology to various car-pooling-related policies are discussed. The paper concludes with a summary of major findings. [Both the methodology used and the analysis of prediction results by market segments are discussed in greater detail by Ben-Akiva and Atherton (1).]

METHODOLOGY FOR SHORT-RANGE TRAVEL-DEMAND PREDICTIONS

The methodology for predicting the changes in travel patterns that will result from short-range transportation options (including car-pooling incentives) is based on the application of disaggregate travel-demand models. These models are based on the multinomial logit, probabilistic choice model, which has been discussed by Domencich and McFadden (5) and Richards and Ben-Akiva (7). The data used to estimate the coefficients of these models are taken from home-interview surveys and represent a cross section of households. The dependent variables of the models are the reported travel choices made; the independent variables are the reported socioeconomic characteristics, engineering measures of travel times and costs, and survey estimates of employment and land-use characteristics in the urban area.

The models consider residential locations and work places as being fixed and predict automobile ownership, choice of mode for the work trip, and frequency, destination, and mode for nonwork travel. Car pooling is explicitly considered as an alternative mode only for work trips. However, the effects of car-pooling incentives on interdependent travel choices and vice versa are also predicted.

To apply these models to the forecasting of changes in travel behavior that will result from alternative car-pooling incentives, a sample enumeration technique is used. In this procedure, a randomly selected sample of households is used to represent the entire population of an urban area. Forecasts are made by applying the