BEHAVIORAL MODELING OF EXPRESS BUS-FRINGE PARKING DECISIONS

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A disaggregate data base was developed to analyze the behavior of commuters based on their choice of using fringe parking and riding the express bus or driving directly to the central business district. Statistical summaries of the information obtained were analyzed and interpreted to provide a basis for selecting explanatory variables and for stratifying mathematical choice models using the logistic function. It was found that separate models should be calibrated for groups of trip makers according to the accessibility of the fringe lot to their zone of residence. The models were then calibrated by using alternative methods for specifying the time and cost differentials between the options of driving directly to the central business district and using the bus service. In this respect, models were calculated to predict the probability of choosing the express bus as a function of the age and sex of the trip makers, the ratio of automobiles to licensed drivers for their respective households, and the relative times and costs of the competing modes. Evaluation criteria, including statistical tests, were used to select the model strategy that best described the choice situation. Consequently, a model that related time and cost as the difference between modes divided by the average of the two proved best. Finally, the models were used to obtain elasticities of choice with respect to the independent variables and the value of time, which agreed with the theory and the findings of other studies.

•THE express bus-fringe parking concept is an example of a situation in which area-wide travel models that represent an arbitrary automobile-transit choice cannot be directly applied because of the aggregate data base. In such circumstances, the selected transit operation serves only a segment of the travel market along a corridor of the urban area and provides varying levels of service to different residential zones. This problem, therefore, provides an opportunity to use disaggregate behavioral modeling concepts to represent travel behavior for a defined subarea. In this respect, firsthand data can be obtained that clearly relate the available choices.

Accordingly, this paper describes how survey data from a recent fringe parking project, the Parham Express in Richmond, Virginia, were collected and used to formulate a set of hypotheses for constructing a mathematical model of the choice between driving to the CBD or parking at a fringe lot and using the express bus for CBD-destined work trips. Alternative behavioral models based on the logistic function are then formulated, tested, and evaluated.

DESCRIPTION OF STUDY AREA

The fringe parking facility on Parham Road had 178 parking spaces in July 1973 and is located about 8.7 miles (14.0 km) northwest of the downtown area in Richmond, Virginia. The area surrounding the facility is mainly residential, and there is access to some local shopping centers.

The CBD area can be reached either by Interstate 64, which has ramps at Parham Road and Glenside Drive, or by main arterial routes (Broad Street and Patterson

Avenue). Although using the Interstate requires a toll of $0.25, it is generally preferred to using the arterials so that delays due to traffic congestion can be avoided.

The Parham Express bus, which originates at the fringe lot, provides a nonstop trip to the CBD, and has 10 bus departures from 7 a.m. to 9 a.m. The one-way fare is $0.50 compared with $0.35 (on the day of survey) for the regular area routes.

DATA

The system and trip-maker (behavioral) data used in this analysis of travel behavior include

1. System data—highway travel distances; highway travel times; transit costs; transit running times; and excess times (e.g., transit access from parking lot to destination); and
2. Behavioral data—a bus survey and an automobile survey.

The questionnaire used for the bus survey is shown in Figure 1. It was distributed on a weekday at the beginning of the bus trip and collected as riders left the bus, or it was returned by mail. The license numbers of automobile travelers entering the expressway during the same time period (7 a.m. to 9 a.m.) on the two ramps in the vicinity of the fringe lot were recorded. Their questionnaires were mailed. The automobile survey form is shown in Figure 2.

In the bus survey, 302 questionnaires were handed out, and 285 were returned. After incomplete forms were eliminated, 229 usable responses remained.

Because license numbers of all vehicles entering the freeway could not be recorded, traffic counters provided a control total for the automobile users that could be associated with the 302 bus users. Of the 4,030 automobile trips, 1,165 valid questionnaire responses, a 28.9 percent sample, were obtained. Of this sample, 381 responses concerned work trips to the CBD. It was further assumed that the sample was representative of the trip end distribution of the total population and, accordingly, the 381 responses represented a 28.9 percent sample of CBD-destined work trips by automobile.

Because the usable automobile responses made up a 28.9 percent sample, a similar proportion of bus-user responses was developed so that the data set would be proportionately representative of the automobile and bus populations, as would be the case for a home-interview survey. Inasmuch as such a requirement may result in a statistical bias, a program was used to randomly select a 28.9 percent bus sample.

Furthermore, because the model is designed to reflect only real choices, captive riders were removed from the data set. Individuals were classified as transit captives if their alternative mode choice was another bus and if they indicated that they could not have used a household automobile to make the trip. Trip makers were considered to be captives of the automobile if they needed cars for their jobs or worked at locations in the CBD that were remote from a transit stop. The development of the data set is given in Table 1.

The transportation system data were obtained from the transit operator and the Virginia Department of Highways and Transportation and were supplemented with traffic engineering measurements.

MODEL FOUNDATIONS

The travel survey data were examined by summary statistics and correlation analyses so that some basic hypotheses could be developed for stratifying the travel market into homogeneous choice groups and so that explanatory variables for structuring a model could be specified. The results, combined with information from previous efforts, were then implemented to derive a modal-choice model.

The potential explanatory variables examined in terms of sample means and

Figure 1. Bus survey questionnaire.

THE FOLLOWING QUESTIONS CONCERN THE BUS TRIP YOU ARE NOW MAKING

If possible, please fill out this questionnaire during this trip and return it to our personnel who are on board this bus. If this is inconvenient, please fill out this questionnaire at your pleasure and return it in the postage-paid envelope.

FOR OFFICIAL USE ONLY

1. Whe did you initially begin your trip?

____
(specify address - number and street name)

2. Was the place you came from: (check one)
___ home
___ work ___ other (specify) ____________

3. Trip purpose. The reason for this trip was: (check one)
___ return home ___ shopping
___ work ___ recreation
___ chool ___ other (specify) ____________

4. Time you began your trip: _______ A.M.

5. How did you get to the Parham Road Lot to board this bus?
___ drove and parked ___ another bus
___ car passenger-car parked ___ walked, how many minutes ___
___ dropped off-car not parked ___ other (specify) ____________

6. What time did this bus leave the Parham Road Lot? ________ A.M.

7. Where will you get off this bus? (check one)
___ 8th & Clay ___ Main & 11th
___ 9th & Broad ___ Main & 10th
___ Broad & 10th ___ Main & 8th
___ Broad & 12th ___ 7th & Franklin
___ Broad & 14th ___ 7th & Grace
___ 14th & Franklin ___ 7th & Broad
___ 14th & Main ___ 7th & Clay

8. How will you get to your destination after leaving this bus? (check one)
___ walk, how many minutes _____ ___ taxi
___ another bus ___ other (specify) _________

9. What is your final destination?

____
specify address (number and street name) or building

10. Time you expect to arrive at your destination: ________ A.M.

11. If this bus service were not available, how would you make this trip?
___ drive a car ___ another bus
___ ride as a car passenger ___ other (specify) _________
___ participate in a carpool

12. If you drove a car or rode as a car passenger for this trip in the past, why did you switch to this bus? ____________

13. Do you have any recommendations as to how this bus service could be improved? ____________

14. How many licensed drivers reside in your household? (count yourself) ___________

15. How many cars are owned by members of your household? __________

16. Could you have used one of the cars to make this trip? ___yes ___no

17. Please indicate your: Sex: ___Male ___Female
Age Group: ___ under 16 ___ 16-24 ___ 25-44 ___ 45-65 ___ over 65

18. What is the combined annual income of all members of your household?
___$0-$4000 ___$4000-$8000 ___$8000-$12000 ___over $12000

Figure 2. Automobile survey questionnaire.

A vehicle registered in your name was observed entering I-64 eastbound at Glenside Drive between 7:00 a.m. and 2:00 p.m. on August 21, 1973 . It would be appreciated if you or the person who drove that vehicle on this trip would answer the following questions and return the questionnaire in the postage-paid envelope.

FOR OFFICIAL USE ONLY

Errors in recording license plates do occur. If this form was sent to you by error, please check here and return ____. Otherwise, please continue.

1. Where did you begin this trip?

   ____

   specify address (number and street name)

2. Was the place you came from: (check one)
   ___ home
   ___ work ___ other (specify) ______________

3. Trip purpose. The reason for this trip was: (check one)
   ___ return home ___ shopping
   ___ work ___ recreation
   ___ school ___ other (specify) ______________

4. Time you began your trip: ______ /P.M.

5. What was your final destination?

   ____

   specify address (number and street name) or building

6. Time you reached the above address: __________ A.M./P.M.

7. What was the vehicle parking cost? $______ per _______

8. After you parked the automobile, how did you get to your final destination?
   ___ walk, how many minutes ___ ____ taxi
   ___ bus ____ other (specify) ______

9. Do you use your car during the business day? ___ yes ___ no

10. Do you usually make this trip: (check one)
    ___ alone
    ___ carrying passengers, how many? _______
    ___ within a carpool, how many members (count yourself)? ______

11. Could you have used the express bus from the Parham Road Lot for this trip?
    ___ yes, but I chose not to because ______________
    ___ no, because ______________
    ___ not aware of this service

12. Are there any improvements possible regarding the Parham Express bus service which would make it acceptable enough to influence you to use it? ___ yes ___ no If yes, what might they be? ___

    ____
    ____
    ____
    ____

13. How many licensed drivers reside in your household (count yourself)? ____________

14. How many autos are owned by members of your household? ________

15. Please indicate your: Sex: ___Male ___Female
    Age Group: ___under 16 ___16-24 ___25-44 ___45-65 ___over 65

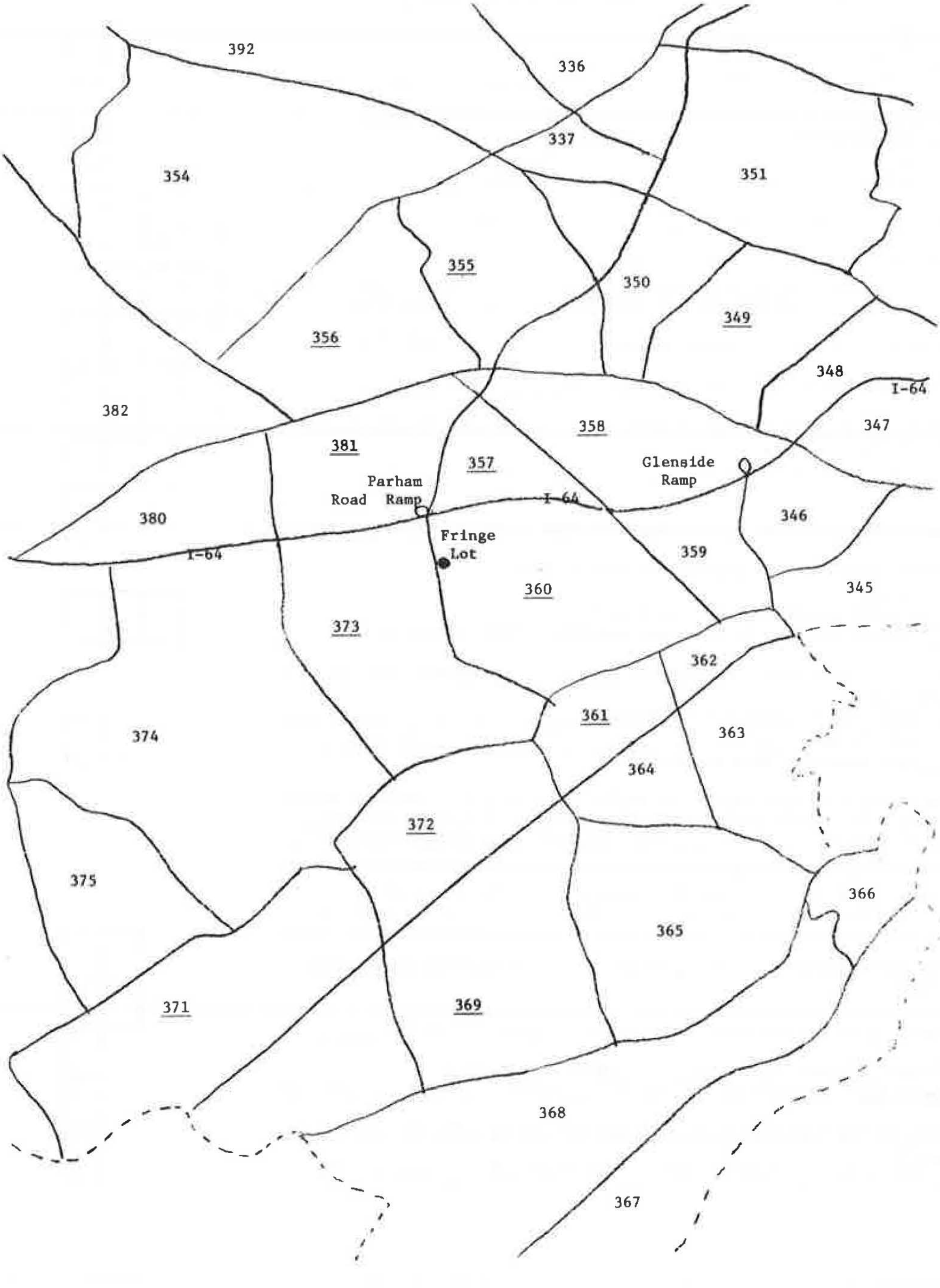
16. What is the combined annual income of all members of your household?
    ___$0-$4000 ___$4000-$8000 ___$8000-$12000 ___over $12000

Table 1. Summary of data set.

Item	Bus Trips		Automobile Trips	
	Number	Percent	Number	Percent
Total trips	302	100	4,030	100
Valid questionnaires	229	94	1,165	29
CBD trips	229	76	381	
Choice CBD trips	222	74	223	
Number used for model calibration	87	29	223	29[a]

[a]223 is 29 percent of CBD-destined and choice automobile trips.

Figure 3. Parham Express market area.



correlation analyses were automobile ownership (number of automobiles per number of licensed drivers), household income, sex, age, travel cost, residence zone, and travel time. Initially, all variables except automobile ownership and household income were determined to be significant.

Automobile Ownership

The distribution of automobile ownership for those who drive to the CBD (1.8 automobiles per household) does not differ significantly from that of express bus riders (1.9 automobiles per household). However, automobile ownership per se is not sensitive to the number of household members who have access to cars, i.e., the licensed drivers. In this respect, the presence of more licensed drivers than automobiles places a constraint on the availability of cars to household members, and this may encourage household members to consider alternative modes. Therefore, it was hypothesized that, for a given household, the ratio of automobiles owned to the number of licensed drivers may be a more significant variable than automobile ownership. This hypothesis was tested by using a chi-square test that showed that the distribution of the aforementioned ratio for the bus sample was significantly different from that of the automobile sample at the 0.01 level. Therefore, the ratio of automobiles owned to the number of licensed drivers for a given household was selected for testing in the model.

Sex

Female commuters showed a higher propensity to use the express service than did males. It was assumed that the differing percentages of females in the bus and automobile populations (41.7 versus 35.5 percent) warranted that the sex variable be included in the model testing.

Household Income

There was almost no difference in the household income distributions of automobile and transit commuters. Both distributions were characterized by very high percentages at the >$12,000 level and a very low percentage at the <$4,000 level. This variable was therefore excluded from further consideration.

Age

The data showed that age should be considered for inclusion in the model. Variations in behavior were observed among the following age groups: 16 to 24 and 45 or over versus 25 to 44.

Travel Cost

Cost figures for automobile travel were estimated by summing the freeway toll ($0.25), half of the parking cost, and an assumed out-of-pocket operating cost of $0.04/mile ($0.025/km). (In the case where there were passengers as well, it was assumed that riders shared the travel cost with the driver.) Transit travel costs consisted of the $0.50 fixed fare and the cost associated with getting to the lot. A statistical analysis was carried out to determine whether the distribution of travel cost for the bus population was different from that of the automobile population. The travel cost figures for the automobile sample were greatly dispersed with a standard deviation of $0.296, whereas the travel cost values for the bus sample varied only slightly from the average (standard deviation = \$0.043). The t-tests and F-tests further indicated that both the mean and the variance of the bus population were significantly different from those of the automobile population at a 0.01 significance level. Therefore, travel cost was selected as a variable for the modal-choice model.

Location of Residence Zone

The set of zones that made up the market area for the service is shown in Figure 3. Only 16 zones exhibited substantial trip productions, and four of those 16 had very low express bus ridership. These observations were assumed to arise from the following factors:

1. These zones were relatively far from the fringe lot.
2. There were two local bus services available, besides the express, to some of these zones. Therefore, the residential area assumed to make up the market area for the service consisted of 12 zones that accounted for 78.9 percent of the automobile trips and 84.2 percent of the express bus trips. Table 2 gives the modal split between automobile and express service in these selected zones (shown by underlined numbers in Figure 3).

The effect of accessibility to the fringe lot from the zone of residence was also examined as an influence on travel behavior. For each zone, minimum time paths to the CBD and to the lot were plotted. The zones were then grouped into accessibility groups 1, 2, and 3 according to the following criteria:

1. The zone is located adjacent to the zone where the lot is;
2. The zone's minimum time route to the CBD falls close to the fringe lot; or
3. The lot is out of the way of the best route to the CBD from the residential zone.

Analysis of the data showed that accessibility of the fringe lot was highly related to the transit use in a zone because relatively high split numbers for transit were indicated for zones convenient to the fringe lot. Accordingly, it was concluded that some measure of the accessibility of the lot from the residence zone should be reflected in the model.

Travel Time

The survey provided information on the perceived time for each trip, and, because the engineering data were incomplete, the former was interpreted for use in the models. A chi-square test was carried out to compare the automobile population with the bus population in relation to perceived travel time. The test indicated a substantial difference in distribution at the 0.005 significance level. The results of a t-test at the 0.005 significance level further showed that the automobile and bus populations also differ with regard to mean values of travel time.

Total travel time has been broken into running time and excess time in some current research (1, 2). Excess time includes walking, waiting, and transfer time and is usually weighted by a factor greater than 1. [The Washington model (3) used 2.5.] A similar approach with varying forms of the time variables was considered in the model development.

These observations from the survey data provided a set of variables for consideration in the model development.

MODEL APPLICATION

Models were estimated by using logit analysis where the basic form is

$$P_b = \frac{e^{G(x)}}{1 + e^{G(x)}} \quad (1)$$

where P_b is the probability of choosing the express bus, and G(x) is a linear function of explanatory variables for which the parameters can be estimated by the maximum likelihood method.

The s-shaped graph of the logit model agrees with the common assumption that the marginal utility of increments of a commodity, say time difference, is highest in regions where the difference between the two modes is close to zero and, conversely, approaches zero in regions where the difference is substantial. The logit methodology can also be conveniently used to derive some important microeconomic properties of the behavior group, i.e., elasticities and values of time.

The models presented here were calibrated with a computer program developed by J. G. Cragg, University of British Columbia, and adapted to the CDC 6400 by Peter R. Stopher, Northwestern University. Three models were calibrated, all of which included the socioeconomic variables cited previously, but they differed from each other by the nature of the specification of the time and cost measures. A surrogate measure of the accessibility of the residential zone to the lot was initially entered as a dummy variable to reflect the three accessibility groups described earlier. The estimated coefficient of the accessibility variable was found to be highly significant, and, for practical reasons, separate models were calibrated for each accessibility level as well as one model with all the data.

A listing and definition of all of the variables used in developing the models are given in Table 3. The three types of models presented are referred to by terms indicative of the manner in which the time and cost measures are treated; they are the difference model, log-of-ratios models, and relative values models.

The criteria used to evaluate the credibility of the alternative models included the sign of the coefficients, the significance of the parameters, the probability of choice at zero difference, and the predictive ability of the models.

The first step is a check on the rational performance of the model. The second evaluation, which relates the significance of the parameters, uses the t-test and the chi-square test. The t-test shows the significance of each parameter individually (4), whereas the chi-square method tests the hypothesis that all coefficients except the constant are equal to zero against the hypothesis that they all do not have zero values (5, 6).

The probability of choice at zero difference given by the model is considered relative to the basic premise of the logit model that states that, when the values of the system characteristics are equal for the competing modes, the trip maker is indifferent to either mode. In application, however, this figure is difficult to attain because all factors influencing travel behavior are not reflected in the model. Accordingly, a slight bias in favor of the bus mode was envisioned for accessibility group 1, and a high probability of automobile choice was anticipated for accessibility group 3. The group 2 models were expected to give values close to 0.50 because there appeared to be no real advantage to either mode for those trip makers.

Finally the ability of the models to predict observed travel behavior was considered. One way to accomplish this was to compare the expected value of the estimated number of users with the number of observations from the data set. Here the percentage of predictive error, e_1, is defined as

$$\left| \frac{\text{actual number} - \text{estimated number}}{\text{actual number}} \right| \times 100$$

A further test is suggested by Watson (7) and involves using one-half of the data to calibrate the models and the other half to study predictions. This prediction error, e_2, is computed in a fashion similar to the way in which e_1 was.

Table 2. Modal split between automobile and express service in origin zones.

Origin Zones	Modal Split		Origin Zones	Modal Split	
	Automobile	Bus		Automobile	Bus
349	0.93	0.07	361	0.88	0.12
355	0.85	0.15	369	0.66	0.34
356	0.89	0.11	371	0.66	0.34
357	0.85	0.15	372	0.80	0.20
358	0.90	0.10	373	0.72	0.28
360	0.64	0.36	381	0.78	0.22

Note: Average automobile split = 0.80; average bus split = 0.20.

Table 3. Variables used in models.

Variable Description	Symbol
Independent variable	
Sex—0 = female; 1 = male	x_1
Age—0 = (25-44); 1 = otherwise	x_2
No. household automobiles / No. licensed drivers	x_3
Running time difference	$x_4 = (RT_a - RT_b)$
Excess time difference	$x_5 = (ET_a - ET_b)$
Total cost difference	$x_6 = (C_a - C_b)$
Natural log of ratios of total times	$x_7 = \ln (T_a/T_b)$
Natural log of ratios of total costs	$x_8 = \ln (C_a/C_b)$
Total time difference divided by average total time	$x_9 = \frac{T_a - T_b}{(T_a + T_b)/2}$
Total cost difference divided by average total cost	$x_{10} = \frac{C_a - C_b}{(C_a + C_b)/2}$
Dependent variable	
Automobile transit choice	P_b
Calibration	
For automobile trips	$P_b = 0$
For bus trips	$P_b = 1$
Application, probability of bus choice	P_b

Note: a = automobile measure; b = bus measure. Accessibility groups 1, 2, and 3 were also used in model development.

Table 4. Difference model.

Item	Estimated Model Coefficients			
	Accessibility Group 1	Accessibility Group 2	Accessibility Group 3	All Data
Independent variable				
x_1	-1.1080	-1.3083	0.70169[a]	-0.4901[a]
x_2	1.1720[a]	0.3846[a]	1.5550	1.0520
x_3	-2.1763	-4.3375	-3.4558	-3.2798
x_4	0.1083	0.2383	0.2326	0.1891
x_5	0.1530	0.3752	0.5803	0.2262
x_6	0.0378	0.0490	0.0591	0.0369
Constant	2.1544[a]	4.5191	0.99814[a]	2.6365
Evaluative measures				
χ^2	23.51	28.77	35.84	80.04
e_1, percent	0.06	0.55	0.19	0.28
P_b at zero difference	0.573	0.500	0.251	0.48
e_2, percent	—	—	—	8.02

[a]Indicates that the variable or constant was nonsignificant at the 0.05 level.

Difference Model

The system characteristics used in the difference model given in Table 4 include the running time, excess time, and cost differences. The values for the reported mode (choice) were obtained directly from the survey responses concerning perceived times and costs, and the measures for the alternative mode were estimated by averaging the perceived data for each zone. The use of averaged data for the alternate mode presents potential problems; but, inasmuch as the survey provided no information on the alternative choice and the available engineering data were incomplete, this was the only option available.

Estimated coefficients exhibited the expected signs. All of the system variables were significant at the 0.05 level with the exception of the excess time, which was significant at the 0.10 level for group 3. Chi-square tests proved the hypothesis that the coefficients were significantly different from zero at the 0.005 level. Probabilities of choice at zero difference were in agreement with the prior assumption (i.e., the bias of the accessibility groups). The model predicted the original data almost perfectly; however, the value of e_2 was the highest among the three models.

Log-of-Ratios Model

The difference model makes the assumption that the modal-choice decision is based strictly on the absolute values of the differences in times and costs. In this respect, the model implies that the choice between travel times of 15 and 20 min is equivalent to a choice between 35 and 40 min when all other variables are kept constant. The log-of-ratios model given in Table 5 was introduced to correct this fault, and it predicted two significantly differing transit choice probabilities for the hypothetical travel times indicated previously (0.214 and 0.430 respectively). The time and cost variables were calculated by taking the natural logarithm of the ratio of automobile time and cost to bus time and cost. Also, inasmuch as the automobile data included some observations in which excess time was equal to zero (i.e., $\ell n 0 = -\infty$), total time figures rather than a breakdown of running time and excess time were used in this model.

In the log-of-ratios model, all coefficients exhibited the hypothesized signs. All the system variables were significant at the 0.05 level. Age and sex failed the significance test for the group 2 and group 3 models respectively. The chi-square test was satisfactory at the 0.05 significance level. Probabilities of choice at zero difference were as hypothesized. The model predicted the original data almost perfectly, and the value of e_2 was the second best among the three models.

Relative Values Model

A further model form, given in Table 6, was designed to use time and cost differences relative to total cost and time. However, there was no evidence available to indicate whether the actual mode taken or the alternate mode was being considered as a base by the trip makers. Therefore, it was assumed that the average of the total times from the alternative choices would be suitable.

The general characteristics of this model, although slightly better, were similar to those of the log-of-ratios model. The values of the estimated coefficients were within 8 percent of those of the latter model, and similar variables were insignificant. The relative values model satisfied the expected sign test and had the lowest e_2 value. Probabilities of choice at zero difference complied with the hypothesized trend.

Selection of Best Model

After the three alternative models were introduced, the next task was to select a best model for determining elasticities and values of time. In view of the criteria

Table 5. Logarithm-of-ratios model.

Item	Estimated Model Coefficients			
	Accessibility Group 1	Accessibility Group 2	Accessibility Group 3	All Data
Independent variable				
x_1	-1.3291	-1.2840	0.8103[a]	-0.5259[a]
x_2	1.1447	0.3235[a]	1.4357	1.0838
x_3	-2.3681	-3.8899	-4.6697	-3.5466
x_7	4.1488	10.525	8.3734	6.4931
x_8	3.3688	4.4247	4.5293	3.3654
Constant	2.3994	4.3030	2.0240[a]	2.7782
Evaluative measures				
χ^2	29.60	32.41	35.96	93.7
e_1, percent	0.13	0.15	0.18	0.61
P_b at zero difference	0.559	0.543	0.245	0.455
e_2, percent	—	—	—	3.2

[a]Indicates that the variable or constant was nonsignificant at the 0.05 level.

Table 6. Relative values model.

Item	Estimated Model Coefficients			
	Accessibility Group 1	Accessibility Group 2	Accessibility Group 3	All Data
Independent variable				
x_1	-1.3416	-1.3092	0.8207[a]	-0.5294[a]
x_2	1.1430	0.3443[a]	1.4384	1.0883
x_3	-2.3536	-3.9319	-4.7517	-3.5738
x_9	4.2932	10.899	8.5377	6.6795
x_{10}	3.3990	4.7533	4.7783	3.5717
Constant	2.3732	4.3230	2.0465[a]	2.7839
Evaluative measures				
χ^2	30.05	33.03	36.20	94.8
e_1, percent	0.15	0.16	0.17	0.63
P_b at zero difference	0.554	0.532	0.236	0.451
e_2, percent	—	—	—	1.59

[a]Indicates that the variable or constant was nonsignificant at the 0.05 level.

Table 7. Models ranked by performance and reliability criteria.

Model	Significance of Individual Variables	Chi-Square Test	Expected Sign	Prediction (e_1, e_2)	Probability at Zero Difference	Final Ranking
Relative values	1	1	OK	1	OK	1
Log of ratios	2	2	OK	2	OK	2
Difference	3	3	OK	3	OK	3

Table 8. Aggregate elasticities of choice probability.

Variable	Transit	Automobile
Automobile time	2.81	-1.11
Transit time	-2.80	1.11
Automobile cost	1.39	-0.55
Transit cost	-1.51	0.60
Number of automobiles/ number of licensed drivers	-1.47	0.58

discussed earlier, the models were ranked and the relative values model, as given in Table 7, was selected as the best. Thus, this model primarily is used in the following microeconomic analyses.

Descriptive Measures of Travel Behavior

The aforementioned models derive basic descriptive measures of the travel behavior of the sample group, namely, elasticities of choice and the trip maker's value of time. The elasticity ($\epsilon_{m,k}$) is a dimensionless number defined as the relative percentage change in the probability of the specified choice that results from a 1 percent change in any explanatory variable. Mathematically, the elasticity of the probability of using mode $m(p_m)$ with respect to a given variable X_k is stated as

$$\epsilon_{m,k} = \frac{\partial p_m/p_m}{\partial X_k/X_k} \tag{2}$$

With the relative values model, the probability of using the express bus relative to using all of the system variables and the ratio of the number of automobiles to number of drivers were elastic. However, automobile choice was elastic only with respect to time (i.e., $\epsilon_{m,k} > 1$). The elasticities computed for each mode are given in Table 8. These values can then be applied to estimate the effect of various policy and social changes on modal choice. For example, the analysis shows that a 1 percent increase in transit cost will lessen the former probability of using that mode by 1.51 percent.

The value of time is found by calculating the change in cost due to a unit change in the time variable and by keeping all other variables, including the choice probability, constant. Accordingly G(x) must remain unchanged if the choice probability remains constant. Given this fact, it has been shown that (8)

$$\frac{dC_i}{dT_j} = -\frac{\partial G(x)}{\partial T_j} \bigg/ \frac{\partial G(x)}{\partial C_i} \tag{3}$$

where i = a, b; j = a, b; a = automobile; b = bus; and dC_i/dT_j = the rate of commodity substitution and, accordingly, the change in the value of cost of mode i (dC_i) for a unit change in the travel time of mode j(dT_j) is the value of travel time.

The value of travel time for the study area was estimated by substituting the appropriate terms for each mode in the relationship discussed, which results in four expressions of the value of travel time for average sample values. These four values of time relate to changes in the cost associated with each of the two competing modes, which are due to a unit time change in either mode. As Watson (6) argues, it can be assumed that the trip makers will perceive a change in bus and automobile costs due to a travel time change for either mode. Therefore, it was assumed that the average of the two values for each mode would be a reasonable estimate of the value of time for that particular mode. Under this assumption the values of bus and automobile time were calculated to be \$2.10/hour and \$2.69/hour respectively. This indicated that bus users value time differently than automobile users do. Furthermore, the values of travel time were found to be 39.6 percent and 50.8 percent of the wage rates for the bus and automobile users respectively.

Inasmuch as travel time was not broken into running and excess time in the relative values model, the difference model was used to estimate the values of these times separately. The values obtained were \$2.33/hour for the running time and \$4.55/hour for the excess time. This amounted to 44 percent and 85.8 percent of the wage rates respectively. However, the accuracy of these figures may be questionable because the difference model was comparatively less reliable, as was discussed previously.

SUMMARY OF FINDINGS AND CONCLUSIONS

Disaggregate behavioral models of the choice between driving to the CBD and using an express bus-fringe parking service proved highly successful. This conclusion is based on the statistical tests and other evaluation methodology that showed that models calibrated with all the survey data closely predicted the observed behavior of the entire sample and that models calibrated with only half of the data predicted the behavior of the remainder of the sample. The findings showed that one method of specifying the system variables of time and cost (the relative values model) performed slightly better than the other two. This indicates that the better the model represents the way individuals perceive the differences among the attributes of competing modes, the more reliable the model becomes. The variations in behavior among trip-maker groups based on the accessibility of their residence zone to the lot are significant and can be used to determine the service area for proposed lots. They should also be of use in the design of feeder lines where they are being considered.

The survey design, by which data were collected directly from travelers on the competing modes, proved adequate for the purposes of developing the model. It is envisioned that the model developed here can be applied in planning new express bus-fringe parking services with a minimal amount of socioeconomic and system data (Table 9). Recent origin-destination study data should also satisfy these needs.

The significant variables in the models included sex, age, time, cost, and the ratio of household automobiles to household drivers, all of which were recommended in the preliminary analysis of the data. The income variable, which was initially nonsignificant, was similarly dismissed by t-tests for models in which it was included to test the prior analysis. This finding is appropriate because this was not an areawide study, in which income usually becomes appropriate, but it was a study of a relatively homogeneous suburban area.

Finally, the models gave the measures for elasticities of choice in relation to the various independent variables and for the value of time. They were consistent with theory and the findings in other studies.

The models developed here should be tested to see how well they predict the behavior of trip makers for similar services in other areas. They should also be used in the planning stages of a proposed project so that their effectiveness as a planning tool can be evaluated.

A logical extension of binary-choice modeling techniques is to consider the submodal split of access modes to the express bus such as walking, bicycling, feeder buses, and kiss and ride. Subsequently, appropriate multimodal techniques should be applied and tested for their validity relative to that of the binary models.

Improved problem-oriented surveys, such as the one described in this paper, or origin-destination surveys for a selected subarea should be carried out for similar services and should be expanded to include psychological data on trip-maker perceptions

Table 9. Data requirements for model application.

Data	Source
Socioeconomic	
Number of zonal work trips terminating at destination zone of service (e.g., model output, number of CBD work trips)[a]	Census or gravity
Zonal distribution of workers by sex	Census
Zonal distribution of workers by age	Census
Average zonal automobile ratio (number of household automobiles to number of licensed drivers)	Census
Transportation system	
Average cost per trip via each alternative	Trip assignment model
Average total travel time per trip via each alternative	Trip assignment model
Zonal classification relative to lot accessibility (3 groups in Richmond model)	Trip assignment model

[a]If only the expected proportion of CBD-destined drivers who will change to the bus mode is desired, then this information is not required.

of comfort, convenience, and other subjective system measures. In addition, the survey respondents should be asked questions dealing with the competing modes as well as with their chosen mode. These additional data are necessary to add to the behavioral accuracy of the models.

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