TRAVELER PREFERENCE FOR FARE ALTERNATIVES AS A TRANSPORTATION PLANNING INPUT

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This paper deals with the effect of fare policy and transit service plans on mode-choice behavior. These issues were studied in the context of coordinating a new rail rapid transit service in San Francisco with the existing surface bus system in order to maximize the overall service level. To aid the process of simulating the effects of various bus and rail service plans and joint fare structures under study, a disaggregate model of sub-modal-choice behavior was developed. The model was calibrated with data collected in a field survey of bus patrons. These data were used to estimate the relative influence of fare level and time savings on sub-modal-choice behavior and to forecast the probable extent of rail rapid transit usage by current bus riders. Although the specific questions posed in this study were geographically unique, the underlying technical and policy issues could be applied to other similar situations involving the introduction of a new transportation service or facility.

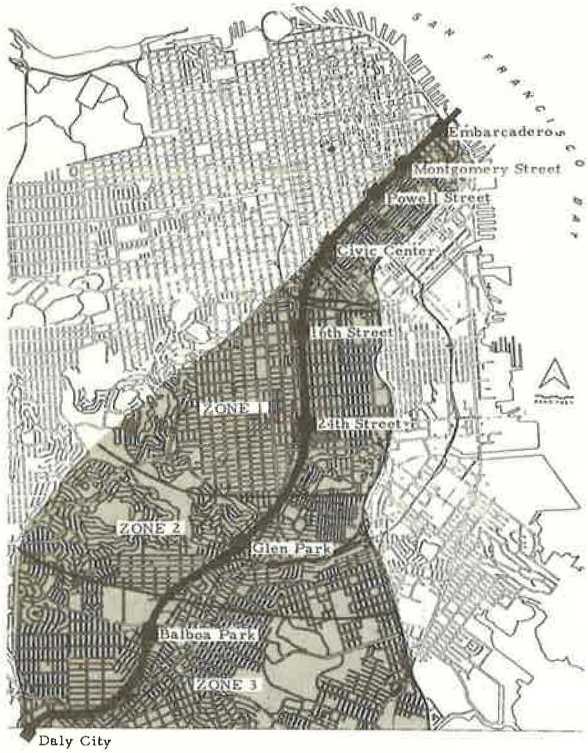
•PRIOR to the introduction of rail rapid transit service by the Bay Area Rapid Transit (BART) District in the San Francisco Mission corridor, an extensive analysis of service options was conducted. The analysis focused on a comparison of alternative service and fare plans for coordinating the bus lines and BART service. An integral part of the evaluation procedure was the development and calibration of a disaggregate model of sub-modal-choice behavior. That model is described in this paper. The survey research design that was used to estimate the relative influence of fare level and time savings on the sub-modal-choice process is reviewed in detail. Although the specific questions stemming from the introduction of BART service are geographically unique, the underlying technical and policy issues discussed here may be generalized to a wide variety of situations.

THE STUDY AREA

Figure 1 shows the 7-mile-long BART system within San Francisco, the 4 downtown stations, the 4 stations within the Mission corridor proper, and the terminal station in Daly City. The study area encompassed roughly one-third of the land area of the city of San Francisco and contained more than 200,000 persons in 1970. The inner area in particular included a high proportion of ethnic minorities, predominantly of Mexican-American descent; population density was moderate to high, and much of the housing was multiple-unit structures. Almost 40 percent of the residents owned no automobile in 1970.

At the time of the study (November 1972) the buses, streetcars, and trolley coaches of the San Francisco Municipal Railway (MUNI) carried almost 24 million annual passengers in the area to be affected by BART service. During peak hours, MUNI provided on the order of 6,000 coach seats through the Mission corridor. Operation of BART was to commence in September 1973 on the San Francisco line. Thus, with an additional 21,000 seats available in each direction during the peak hour, a substantial impact on MUNI was expected.

Figure 1. Study area.



FARE POLICY ISSUES

The MUNI fare was 25 cents anywhere within the city limits; transfers were free. Limited peak-period express bus service was provided for a premium fare of 35 cents. BART adopted a graduated fare based on distance; the minimum fare was 30 cents. A BART patron could ride between any of the stations in San Francisco for the minimum fare.

Depending on the degree of joint-fare discounting between MUNI and BART, a combined MUNI-BART round trip to downtown San Francisco from the Mission corridor might cost from 60 cents to $1.10. The 60-cent fare represented the possibility of a free MUNI feeder bus, and the $1.10 fare was the full fare for both MUNI and BART. A passenger using only MUNI to get downtown would have a corresponding round-trip fare of only 50 cents. The wide array of potential fares in combination with the relatively high proportion of low-income groups in the Mission corridor suggested that price sensitivity could be highly significant in influencing choices between BART and MUNI. In turn, traveler mode-choice decisions have an important bearing on the requirements for feeder bus and other surface transit routing and service levels, operating requirements, and fiscal positions of MUNI and BART. Thus, a major element of this study design focused on estimating price sensitivity in traveler decision-making.

STUDY DESIGN

The study design entailed specification of a series of models and an evaluation framework for judging the relative performance of alternative transit route, service level, and fare plans. Five major steps were followed.

1. An estimate was made (in which data from previous studies were used) of travel demand in the study area and the modal split between automobile and transit.

2. A transit sub-modal-split model was specified to estimate the number of transit trips that would use BART and the number that would continue to use MUNI.

3. A field survey was conducted to obtain data for calibrating the time and price variables in the sub-modal-split model.

4. Operating cost and service evaluation models were developed to determine performance measures for each alternative. Both direct traveler benefits and estimates of community benefits were considered.

5. Specific transit networks, service levels, and fare plans were delineated, and the models were applied to evaluate each of the alternatives.

Since the primary purpose of the project was to develop service coordination plans, primary attention focused on the submodal split of travel between bus and rail modes rather than on the absolute transit patronage level. Field studies of traveler preferences were limited, therefore, to current MUNI riders.

Specification of the sub-modal-split model form and structure was developed after a literature review was made of traveler mode-choice behavior research. The model chosen included variables reflecting relative service quality attributes of the available mode alternatives and socioeconomic characteristics of the traveler. Because of the large number of variables included in the model specification, a combination of a priori selection of coefficients from empirical data and field survey research was used to calibrate the relations. Elaboration of the model specification and design is presented in the next section of this paper.

An assumption was made that the number of people who would use transit had been determined. The process involved splitting those people among the transit modes, e.g., best BART-only route, BART-MUNI combination route, and MUNI-only route. The interzonal cost impedance for each of the modes was estimated so that the probability of a traveler choosing each alternative could be calculated. The sub-modal-split model was defined algebraically as

$$P^M_{ij} = \frac{1}{1 + \left(\frac{C^M_{ij}}{C^B_{ij}}\right)^n} \tag{1}$$

where

P^M_{ij} = probability of choosing MUNI between origin i and destination j,
C^M_{ij} = generalized cost impedance via MUNI between i and j,
C^B_{ij} = generalized cost impedance via BART or BART-MUNI between i and j, and
n = constant of calibration.

Recent travel behavior research has revealed significant information about many of the factors influencing choice of travel mode. From this research has evolved the concept of "generalized cost" impedance, which represents the relevant transportation system attributes travelers perceive in making travel decisions. Each traveler is presumed to behave according to a unique set of circumstances (e.g., travel time, fares, walking and waiting, socioeconomic attributes), which implies an individual weighing of the various attributes. In the development of a travel model, we seek to determine the aggregate behavior of travelers and use a concept of individual travel behavior to guide the specification of the model. The generalized cost concept provides a framework for inclusion of transportation system variables that people apparently take into account when making travel decisions and that can be used to analyze alternative plans and policies (1).

The generalized cost impedance, C^k_{ij}, was defined as

$$C^k_{ij} = a_1 + a_2 + a_3 + a_4 + \gamma_k \tag{2}$$

where

C^k_{ij} = generalized travel cost between origin i and destination j by mode k,

γ_k = residual mode bias factor for mode k,
a_1 = weighing coefficient for in-vehicle time,
a_2 = weighing coefficient for access time,
a_3 = weighing coefficient for waiting and transfering time, and
a_4 = weighing coefficient for travel cost.

a_2/a_1 is the perceived weighing of access time relative to in-vehicle time. The residual mode bias factor, γ_k, is incorporated to reflect the influence of other unquantified factors such as comfort, reliability, and privacy on mode-choice behavior. These coefficients and the mode bias factor may be expected to vary for different trip purposes and model specifications.

DESIGN OF SURVEY RESEARCH

The objectives of the survey research phase of the study were

1. To develop a data base suitable for the calibration of the sub-modal-split model,
2. To test the hypothesis that the sub-modal-choice process is sensitive to fare level,
3. To provide insights into the relative importance of nonprice determinants of demand for BART and the differences in demand between socioeconomic and demographic groups, and
4. To forecast the extent of usage of BART prior to the beginning of service.

The specific research objective was to estimate the impact of 3 fare structures on the relative preference of downtown-bound MUNI bus riders for either the existing bus alternative or a BART plus a MUNI feeder bus to the same destination. The fare alternatives examined were 30, 40, and 55 cents for a 1-way trip by BART plus MUNI. The fare for MUNI alone remained at 25 cents.

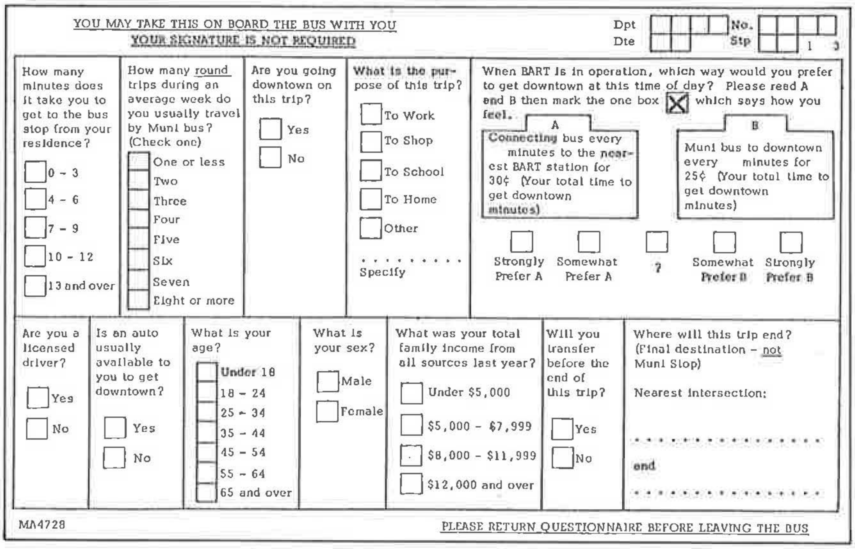
Methodology

The general method adopted for the survey involved exposing randomly assigned groups of MUNI bus riders to the 3 fare alternatives. Similar procedures have long been used to estimate the price elasticity of demand for new durable goods (2). The major limitation of this method is that the choice decision is artificial since no explicit trade-offs are required. In this situation the traveler must trade off higher fares against a possible reduction in travel time and improvement in equipment. So that they would have no problems in comparing a familiar with an untried mode, bus riders were given full information on the relative merits of the 2 alternatives. This was achieved by tailoring the information in the questionnaire to the conditions at the rider's originating bus stop.

An interviewer stationed at a bus stop gave each respondent a questionnaire (Fig. 2). If the respondent was unable to complete the questionnaire before the arrival of the bus, the interviewer would accompany him or her until the questionnaire was completed. Refusals were fewer than 3 percent. Information on wait and downtown travel times from the bus stop via the 2 modes was provided on the questionnaire. The estimates were based on route structures and service levels that the rider would encounter when BART went into service. Only one BART price alternative was presented (randomly) to each respondent.

Comparison of the 2 modes was made by using a 5-point scale reading from "strongly prefer BART plus MUNI" to "strongly prefer MUNI." Additional questions on bus usage, distance from residence to bus stop, trip purpose and final destination, automobile availability, age, sex, and income were asked. Questions that required an evaluation of the alternative modes in terms of attributes such as reliability of service, safety, comfort, and convenience were not included. Although these attributes have been found to influence modal-choice behavior (3), exclusion of these questions was necessary to facilitate completion of the questionnaire by riders while awaiting arrival of their buses. If further information had been requested, this procedure would have been impractical and a more costly interview method would have been required.

Figure 2. Sample questionnaire.



YOU MAY TAKE THIS ON BOARD THE BUS WITH YOU
YOUR SIGNATURE IS NOT REQUIRED

Dpt Dte No. Stp 1 3

How many minutes does it take you to get to the bus stop from your residence?
- 0 - 3
- 4 - 6
- 7 - 9
- 10 - 12
- 13 and over

How many round trips during an average week do you usually travel by Muni bus? (Check one)
- One or less
- Two
- Three
- Four
- Five
- Six
- Seven
- Eight or more

Are you going downtown on this trip?
- Yes
- No

What is the purpose of this trip?
- To Work
- To Shop
- To School
- To Home
- Other

. . . .
Specify

When BART is in operation, which way would you prefer to get downtown at this time of day? Please read A and B then mark the one box [X] which says how you feel.

A: Connecting bus every minutes to the nearest BART station for 30¢ (Your total time to get downtown minutes)

B: Muni bus to downtown every minutes for 25¢ (Your total time to get downtown minutes)

Strongly Prefer A | Somewhat Prefer A | ? | Somewhat Prefer B | Strongly Prefer B

Are you a licensed driver?
- Yes
- No

Is an auto usually available to you to get downtown?
- Yes
- No

What is your age?
- Under 18
- 18 - 24
- 25 - 34
- 35 - 44
- 45 - 54
- 55 - 64
- 65 and over

What is your sex?
- Male
- Female

What was your total family income from all sources last year?
- Under $5,000
- $5,000 - $7,999
- $8,000 - $11,999
- $12,000 and over

Will you transfer before the end of this trip?
- Yes
- No

Where will this trip end? (Final destination - not Muni Stop)

Nearest intersection:

. . . .

and

. . . .

MA4728

PLEASE RETURN QUESTIONNAIRE BEFORE LEAVING THE BUS

The validity of the survey procedure was dependent on the degree to which the bus riders (a) received similar information about travel time and wait time differences between the 2 modes (as was presented to the survey respondents) and (b) maintained their attitudes toward the attributes of BART between the time of the survey and the opening of BART in San Francisco.

Sample

The sample was limited to those Mission corridor bus stops attracting 30 or more boarders on inbound buses during the morning peak period (7 to 9 a.m.). Stops with less activity would not economically support an interviewer. Predetermination of boarding activity at each bus stop proved difficult because of substantial errors in the available boarding count data and uncertainties in the estimation procedure. The problem was accentuated by the exclusion of students and elderly persons from the sample because of their eligibility for fare discounts.

A stratified sample in which the interval was inversely related to the number of inbound boarders was drawn from suitable bus stops. The resultant sample contained

11 of the top 30 stops (100 or more boarders),
9 of the next 56 stops (50 to 99 boarders),
5 of the next 57 stops (30 to 49 boarders), and
0 of the remaining 289 stops.

The 289 excluded stops comprised 66 percent of the stops, but contributed only 21 percent of the total MUNI riders. The total response sample consisted of 1,433 interviews of which 1,085 were usable and 348 were unusable. These latter responses were distributed as follows:

Response	Number
Not going downtown	199
No answer; do not know preference answer	67
Age 65 and over after 9 a.m.	34
Miscellaneous other nonusable interviews	48

One drawback of the stratified sampling procedure was an overrepresentation of bus patrons from the densely populated areas closest to downtown. This overremphasis can be seen in the following:

	Total Boarders (7 to 9 a.m.)		Sample (all hours)	
Zone	Number	Percent	Number	Percent
1	5,118	38	618	57
2	3,366	25	174	16
3	4,982	37	293	27
Total	13,466	100	1,085	100

Zone 1 represents the area closest to downtown; Zone 3 is the area farthest away from downtown.

Timing

Fieldwork for the survey was completed between November 2 and 10, 1972. At that time BART had been in operation (weekday schedule, 6 a.m. to 8 p.m.) on the Fremont to Oakland segment of the system since September. Several events that occurred close to the time of the survey and that might have colored respondents' attitude toward the BART or MUNI systems should be noted.

1. The interviewing took place 1 month after a BART train derailed at the Fremont station;
2. Fieldwork was completed prior to the publication of findings by the state legislative analyst regarding alleged safety defects in the BART train control system;
3. During the period of the field survey, no significant media attention was devoted to BART or MUNI;
4. The project team did not publicize information on fares or service levels preceding the interviews; and
5. Throughout the interview period, the weather was good.

Each weekday was equally represented in the sample. The distribution of the questionnaires by time of day corresponded roughly to the pattern of boarding during the hours in which the study was in progress.

DESCRIPTION OF THE DATA

Because of the survey design, each BART fare alternative received equal representation in the sample. In the results, each alternative was presented as the difference, ΔP, between the fare for BART plus a MUNI feeder bus and the MUNI fare. On the average, BART plus a feeder bus provided a modest time savings, ΔT, of 4.4 min. This average varied considerably: 26 percent of the sample saw no time saving, and 20 percent saved 10 min or more. The difference among geographic zones was especially noticeable.

ΔT (min)	Zone 1		Zone 2		Zone 3		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
-7 to 0	279	44.8	0	0	3	1.3	282	25.9
1 to 4	111	18.3	38	21.4	59	27.1	228	21.3
5 to 9	179	29.1	46	26.4	129	43.8	358	32.8
10 to 22	50	7.8	90	52.2	62	27.8	217	20.0
Total	619	100	174	100	293	100	1,085	100

The average time saving was somewhat misleading because (a) the statistics were dominated by the larger sample base from zone 1 bus stops where BART was frequently at a competitive disadvantage and (b) the headways for feeder buses to BART were generally longer than for MUNI downtown buses by an average of 1.4 min. To the extent that respondents perceived these factors as meaning they would have a longer wait for BART service, they would be less likely to choose BART.

Service levels for both transit modes were significantly reduced after the 9 a.m. departure time, thus reducing the average time savings.

(ΔT)	7 to 9 a.m.		9 to 12 Noon		12 to 4 p.m.		Total	
(min)	Number	Percent	Number	Percent	Number	Percent	Number	Percent
-7 to 0	108	20.0	111	32.3	61	30.8	282	25.9
1 to 4	135	24.8	59	16.7	40	19.7	228	21.3
5 to 9	150	27.7	97	28.0	68	33.4	358	32.8
10 to 22	150	27.5	80	23.0	29	13.1	217	20.0
Total	543	100	347	100	198	100	1,085	100

Selected Rider Characteristics

The sample data revealed the following rider characteristics.

1. Of the total number of respondents, 69 percent were going to work and 15 percent were going shopping.
2. The majority of the riders made at least 5 round trips a week.
3. The majority of the riders lived near a bus stop: 42 percent had a 3-min walk, 31 percent had a 4- to 6-min walk, and 12 percent had a walk of 13 min or more.
4. Thirty-nine percent of the respondents transferred during their trips.
5. The majority of the riders (64 percent) did not have automobiles available for their use, although 54 percent of them were licensed drivers.
6. There were almost equal numbers of males (48 percent) and females (52 percent) in the survey sample. The average age was 32 years, and average incomes were low. Approximately 88 percent were below the average 1972 California household income of $11,400, and 27 percent were under $5,000.

PREFERENCE ANALYSIS

An indication of the preference for BART plus a feeder bus was obtained from the marginal distribution of responses to the choice question. Since the least preference for BART was found in zone 1 (which was overrepresented in the sample relative to the population), it was necessary to adjust the marginals by weighing responses in zones 2 and 3 more heavily.

Service	Preference	Sample (percent)	Population After Adjustment (percent)
BART plus feeder bus	Strongly prefer	12.1	13.5
	Somewhat prefer	14.9	16.6
	Not sure	9.1	10.0
MUNI bus	Somewhat prefer	28.1	27.4
	Strongly prefer	35.8	32.5
Total		100	100

A plausible, overall estimate of the population proportion that would switch from the MUNI to BART plus a MUNI feeder bus is the 30 percent who fall into the combined "strongly prefer" plus "somewhat prefer" categories. Excluding the "not sure" category from the estimate allows for the probability that some of those riders who "somewhat prefer" BART would not switch. These combined categories correspond directly to $P_{IJ}^{B} = (1 - P_{IJ}^{M})$ in the sub-modal-split model.

The overall estimate of the proportion of population preferring BART, P^B, masks the effect of fare differences. These differences are given in Table 1. The range of unadjusted entries from 0.43 to 0.17 suggests that the respondents were able to discriminate between the alternatives and that the survey design was sufficiently sensitive to capture the difference.

A further conclusion from Table 1 is that the aggregate results of the sub-modal-choice process are sensitive to fare differences. For example, the degree of preference for BART plus a feeder bus is 44 percent higher at a 30-cent differential. It would seem that when significant time savings are possible (as in zones 2 and 3) riders are not especially sensitive to fare differences increasing from 5 to 15 cents. However, in zone 1 where BART is generally at a time disadvantage, a fare difference is very meaningful.

ESTIMATION OF FARE SENSITIVITY

The analysis discussed in this section is of holding constant other determinants of modal preference, such as time savings, to precisely estimate the effect of fare differences. In addition this analysis will reveal the relative influence of the various determinants of preferences. A 3-step procedure was followed. First, the patterns of interactions among various explanatory variables were identified. This served as the basis in the second step for specifying a multiple regression equation to directly estimate the effect of different fare levels on modal preference; other explanatory variables were held constant. Finally, the data were aggregated across bus stops and fare alternatives in the form used to calibrate the sub-modal-split model. A regression analysis, using the aggregate data set, estimated the strength of the relation of preference and fare level when the unexplained variance due to individual differences was eliminated. The criterion variable in the above analyses, P^B, was in the form of a dummy or dichotomous variable that took the value of 1 when the respondent strongly or somewhat preferred BART plus a feeder bus and 0 otherwise. Similar results were obtained by using the 5-point preference scale. The advantage of the dummy variable formulation was that it required no interval scale assumption and could be used directly in the sub-modal-split model. The drawback was that the distribution of the error term cannot be assumed to be homoscedastic as required by the linear regression model used here. This raised several difficult interpretation problems (4).

The following were used as possible explanatory variables for P^B:

ΔP = difference in fares (5, 15, or 30 cents);
ΔT = difference in elapsed time to get downtown (MUNI minus BART), in min;
ΔH = difference in headways (MUNI minus BART), in min;
TRIPS = number of round trips per week by MUNI bus;
WORK = 1 if purpose of trip was to get to work and 0 otherwise;
TRANS = 1 if transfer was necessary and 0 otherwise;
DEPART = 1 if departure was before 9 a.m. and 0 otherwise; and
INCOME = total family income, in thousands of dollars.

Identification of Interactions

The analysis of the preliminary results in Table 1 suggested there were possible

Table 1. Proportion preferring BART plus feeder bus by zone and fare condition.

	Proportion by ΔP			
Zone	5 cents (n = 343)	15 cents (n = 355)	30 cents (n = 387)	Total (n = 1,085)
1 (n = 619)	0.26	0.18	0.17	0.20
2 (n = 174)	0.41	0.40	0.31	0.37
3 (n = 292)	0.43	0.38	0.26	0.35
Total (n = 1,085)	0.33	0.27	0.22	0.27
Population estimate after adjustment[a]	0.36	0.30	0.25	0.30

[a]Results for zones 1, 2, and 3 were weighted 0.38, 0.25, and 0.27 respectively to adjust for sampling rate bias.

interactions between ΔP and ΔT; that is, ΔP would have a different relation with P^B depending on ΔT. An exploratory data analysis program (5), automatic interaction detector (AID), was used prior to the regression analysis to isolate the ΔT groups in which different relations occurred.

AID is a sequential procedure. At each step it searches all the explanatory variables and finds that variable which, when split into 2 groups, reduces the unexplained sum of square deviations the most. (This is the same as finding the 2 nonintersecting groups that have the smallest within-group variation.) The procedure starts with the total sample and splits it into 2 groups. Further splits are attempted on the resulting groups until either the groups become too small or the groups become homogenous.

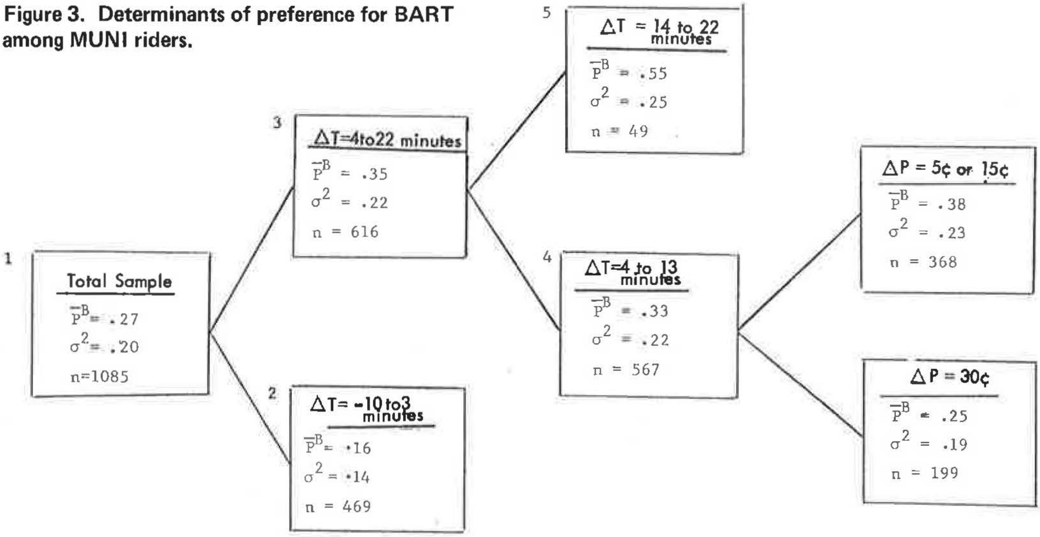
The results of the AID procedure applied to this data set are shown in Figure 3. Each box shows the categories of the explanatory variables used to split the data, the size of the group, the group mean value, and variance of the preference for BART, $\bar{P}^B$ and σ^2.

The results of the AID analysis highlighted the interaction that was only suggested in Table 1. That is, ΔP only had a relation with preference when the time saving a rider expected was between 4 and 13 min. When there was little or no time saving, a hard core group of 16 percent (mostly living in zone 1) still preferred BART regardless of the fare level. MUNI riders may have placed high premium on comfort, which could put MUNI at a disadvantage, or realized that the downtown BART stop was much more convenient to them or that transfers may be easier via BART. Obviously this survey design was unable to shed any direct light on these hypotheses. Analogously, when the time savings via BART were more than 13 min, the fare level also did not matter. Even when time savings were significant, a large proportion (45 percent) still did not choose BART, perhaps because they refused to pay even 5 cents more, had uncertainties about BART, or knew that the downtown BART stop was less convenient than their present MUNI stop.

Regression Analysis

The above AID analysis was used to specify a regression equation that would reveal (a) the relative influence of the various explanatory variables and (b) the ability of the explanatory variables to account for variability in preferences. The interactions isolated above were incorporated in Eq. 3. Logarithmic transformations of the ΔP and income variables did not produce appreciably better results.

Figure 3. Determinants of preference for BART among MUNI riders.



$$P^B = a + b_1\Delta P + b_2\Delta T + b_3\Delta P(\Delta T_d) + b_4\Delta H + \ldots + b_9 \text{ INCOME} \quad (3)$$

where T_d = 1 when ΔT was between 4 and 13 min and 0 otherwise.

The first observation from the regression results in Table 2 is that, with an R^2 of 0.067, the variance in preference is predominantly unexplained. Some of the factors contributing to this situation have already been discussed (primarily that conditions at the end of the trip were not considered). Other reasons for the lack of explained variance in preference include (a) measurements and coding errors, (b) lack of consideration of attitudinal variables (toward the safety, comfort, and convenience of BART relative to MUNI, for example), (c) differences in the perception of the control variables (especially in the believability of the time savings), and (d) the inevitable stochastic element in choice behavior and preferences, which may be especially pronounced here because of lack of information about BART. Results of this magnitude are frequently encountered in studies of individual consumer behavior for these same reasons.

A low R^2 is a problem if there is a possibility of bias in the estimate of the conditional mean preference, given the explanatory variables (6). Such bias would also reduce the value of the data set for the calibration of the sub-modal-split model. The key question is whether there were systematic individual differences favoring either BART plus a feeder bus or MUNI alone in the downtown destination. To test this possibility, a second regression analysis was conducted on a new data set obtained by aggregating the individual responses to the level of the bus stop and fare combinations. Since there were 25 bus stops in the sample and 3 fare alternatives, the new data set contained 75 observations. The dependent variable was the proportion of the sample in each observation group who strongly or somewhat preferred BART. The extent of systematic bias due to the omission of information on the exact destination was revealed by differences in the coefficients of the 2 regression equations for the 2 data sets. These coefficients are compared in Table 2.

The immediate effect of aggregation was to increase the R^2 (adjusted for loss of degrees of freedom) from 0.067 to 0.513. In view of the potential for measurement error and the fact that the upper bound on R^2 (the overall measure of variance explained) is less than 1.0 when a binary dependent variable such as P^B is used (7), the large increase in R^2 was encouraging for it suggested that the explanatory variable set was reasonably complete. More important was the fact that the coefficients for ΔT and ΔP were virtually identical in the 2 data sets (despite the difference in formulation of the dependent variable), and the interaction of these 2 variables was not significant. Thus, we had a clear indication of the relative importance of these 2 explanatory variables: For every 10 min of time saving via BART, the proportion preferring BART (that is P^B) increased between 0.14 and 0.15. Conversely, a fare difference of 10 cents between BART plus a feeder bus and MUNI alone reduced this proportion by approxi-

Table 2. Multiple regression analyses of determinants of preference for BART plus feeder bus.

	Individuals[a]		Aggregation of Individuals for Bus Stop and Fare Combinations[b]	
Variable	Regression Coefficient	t Value	Regression Coefficient	t Value
ΔP, cents	-0.0041	2.6[c]	-0.0040	2.3[c]
ΔT, min	0.015	5.0[c]	0.014	4.5[c]
Δ headway, min	0.001	0.0	0.016	2.0[d]
$\Delta P \cdot (T_d)$	-0.0002	0.1	-0.0023	1.3
Trips per week	-0.002	0.3	-0.030	1.4
Trip purpose	-0.028	0.8	0.004	0.6
Transfer	0.047	1.6	-0.31	0.5
Departure time	-0.001	0.1	-0.002	1.9[d]
Income	0.005	1.2	0.001	1.3
Intercept	0.181		0.240	
R^2 (adjusted)	0.067		0.513	

[a] P^B = 1 if strongly or somewhat preferred BART and 0 otherwise.
[b] P^B = proportion who strongly or somewhat preferred BART.
[c] Coefficient significant at < 0.01 level.
[d] Coefficient significant at < 0.05 level.

mately 0.04. Thus, the real leverage was in time savings. A second conclusion from these results was that no significant source of bias in the data due to omitted variables existed that would affect the use of the data in the calibration of the sub-modal-split model.

SUB-MODAL-SPLIT MODEL CALIBRATION

The sub-modal-split model specified earlier required calibration of 3 coefficients for travel time components, the coefficient for traveler perception of fare relative to family total income, and the exponent for the ratio of generalized cost impedance. Initially, several model calibration formulations were specified and investigated. A nonlinear least squares method was attempted in which survey data aggregated to bus stops were used. This procedure proved unworkable because of the extreme variances encountered and the implied weak statistical relation. A second calibration procedure used each survey observation and assigned a specific probability of using MUNI based on the respondent's answer to the mode and fare preference question. However this method also yielded poor statistical results.

A decision was then made to make a priori estimates for the travel time coefficients on the basis of other empirical research and to calibrate the remaining variables by using the survey data for MUNI riders. Subsequent to the work reported in this paper, the application of maximum likelihood techniques for calibrating a logit model formulation had been initiated. However the results of that work are not yet available.

A Priori Estimate of Travel Time Coefficients

In-Vehicle Time Coefficient, a_1—A value of unity was selected for the weighing factor, a_1, for travel time aboard a transit vehicle, consistent with the interpretation that the aboard-vehicle time is the base time component. All other time components are viewed relative to the unit weight assigned to riding time.

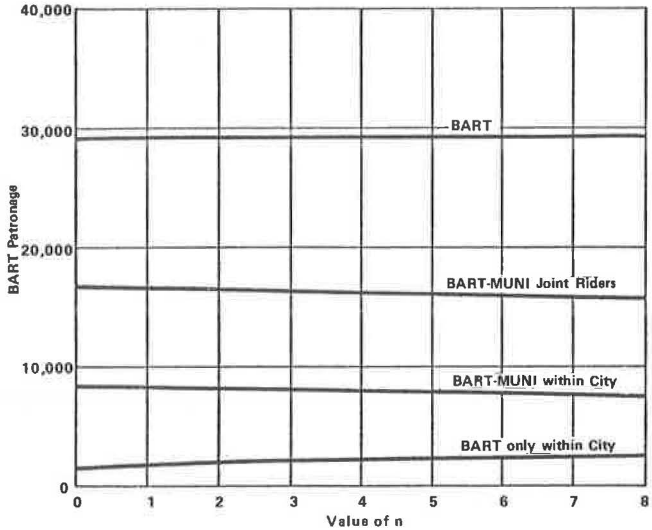
Access Time Coefficient, a_2—Studies of mode-choice behavior indicate that people weigh time for walking more highly than time for riding. Quarmby deduced a value for walking of 2 to 3 times the value for riding in Leeds, England (8). Lisco found a similar pattern in Chicago, where commuters would pay a rate of 12 cents per minute to avoid walking, or 2.8 times the average value of riding time (9). The Regional Plan Association in New York deduced a weight for walking of 3.2 times the value for riding time (10). In work done in New York with respect to the Port Authority Terminal, a walking time weight of twice the riding time seemed to reflect people's behavior most accurately (11). Based on this empirical evidence, a time weight of 2 times the riding time weight was selected.

Waiting and Transferring Time Coefficient, a_3—Waiting for a bus or transferring between transit vehicles has a degree of uncertainty and inconvenience that make such time more onerous than either walking or riding time. Therefore, it is postulated that most travelers attach a higher weight (e.g., disutility) to time spent in waiting or transferring. Although significant empirical research is sparse, one survey in Paris concluded that a weight of 3 times the riding time weight was appropriate (11). This value was adopted as the wait time coefficient.

Time and Cost Equivalents

The generalized cost impedance equation included money costs (fares) and travel time terms. An equivalency to place the money and time impedance elements into common units may be perceived as the value that a traveler places on travel time savings (e.g., the amount that a traveler is willing to pay to achieve unit time savings). A number of studies have investigated the value that commuters place on travel time savings for journeys to work. It appears that commuters value their travel time for work journeys at between 20 and 40 percent of their wage rate. Less is known about the value of time savings for nonwork travel (12, 13, 14). The travel cost reflected in Eq. 2 corresponds to the fare charged for the various mode alternatives (e.g., BART-only, BART and feeder bus, or MUNI-only). For computational ease, the travel time

Figure 4. Sub-modal-split sensitivity to value of n.



components were translated into equivalent cost units by multiplying each of them by a value of time equivalency, V_i, where $V_i = cY_i$, Y_i = median household income of residents in origin i, and c = fraction of income assumed to reflect value of time.

Model Calibration

The model calibration process sought to determine the income fraction c to be used in translating value of time savings and the exponent n for the generalized cost impedance ratio. The calibration used the survey data from 25 MUNI stops as to preference of riders. For each stop, the percentage of all respondents preferring MUNI ("strongly prefer" and "somewhat prefer") and the ratio of impedance were calculated for each fare difference subset.

Experimentation with the value of the exponent n disclosed relatively modest sensitivity (Fig. 4). Therefore, it was reasoned that n could be estimated by using a preliminary value for the income coefficient, c; accordingly, c was set at 0.25 to find an initial solution for n. A value of n = 3 seemed to best replicate respondent preferences. Next, for stops with a large number of samples, the c coefficient was relaxed and successively incremented to solve for the value that best reflected the survey responses to alternative fares. From these analyses, a value for c of 0.17 was determined.

The a priori coefficients and derived values for n and c were incorporated within the model and used to simulate the distribution of travel between BART and MUNI for several different transit service alternatives and fare policies.

Sensitivity Analysis

Each of the a priori-determined coefficients was perturbed individually and in combination so that the effect on the distribution of trips by mode could be examined. Varying the riding and waiting coefficients led to only nominal impact (less than 10 percent) on the distribution of trips by mode. However the access coefficient proved more critical resulting in changes up to 25 percent in the resulting trip allocation by mode as a_2 varied from a value of 0 to 3.2.

No significant compounding effect was observed when the coefficients were varied in combination; the resulting mode allocation reflected additive combinations of the individual sensitivities. By far the greatest sensitivity was evident with respect to c, the fraction of income reflecting value of time. Above a value for c of 0.25, the mode-choice sensitivity was not so pronounced, changing only about 10 percent as c varied up to 0.80. However, for c values between 0.10 and 0.25, the modal split was more sensitive, changing by nearly 25 percent in that interval.

CONCLUSIONS

The research reported in this paper focused on traveler behavior under different mode, service level, and pricing combinations. Two issues were addressed: (a) survey research design and methodology to provide a data base for developing a model of traveler behavior and (b) formulation and calibration of a sub-modal-choice model that reflects traveler behavior and is responsive to policy variables.

The survey research design was reasonably time and cost efficient, although it proved very difficult to establish a reliable sample universe and distribution because of problems of incompleteness and reliability in the available transit boarding count data. The survey effort was restricted to existing bus riders because of budgeting reasons and because it was hypothesized that present bus riders would constitute a very high proportion of travelers affected by the BART and MUNI coordination plans. It would have been desirable to include nontransit users in the survey design, but cost considerations precluded doing so.

The sub-modal-split model calibration results proved less than ideal. Several calibration methods were attempted, but yielded little in the way of useful results toward determining coefficients for the various generalized cost impedance components. Recourse was made to a priori estimates of travel time impedance coefficients on the basis of other empirical research, and survey data were used to determine the remaining model parameters—an income fraction, c, representing value of time relative to median household income and n, the exponent applied to the impedance ratio. Sensitivity tests were executed to examine the effects of varying the coefficients assumed a priori as well as those determined empirically. The sensitivity tests considered the coefficients individually as well as in various combinations. The coefficient for access time and fraction of income equated to value of time, c, proved most sensitive. Compounding effects of changing more than one time variable coefficient were not significant.

Further work toward the objectives of this research is clearly needed. Investigation of different model formulations is in progress, and post-BART data on traveler behavior will permit further assessment and refinement of model relations.

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