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AN APPLICATION OF THE ANALYSIS OF COVARIANCE

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ANALYSIS OF INTENDED BUS USAGE

An Application of the Analysis of Covariance

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Abstract

In order to plan bus operations, it is necessary for transit planners to understand what factors may influence travelers' choice of buses for travels within a city. The proposed methodology involves a hypothetical bus operating situation which was rated by a group of individuals.

Analysis of Covariance technique is employed to generate information on travel behavior when no past travel data are available. The technique involves:

(1) evaluating people's sensitivities to specific service characteristics when stating intentions to use transit systems such as conventional bus service.

(2) assessing differences among various population segments in their sensitivity patterns towa ds transit servic characteristics.

Results from the application of the technique to attitudinal data collected by the Orange County Transit District indicate that transit service characteristics can influence, independently and jointly, respondents' stated intentions to use buses.

Differences in the sensitivity pattern were determined for five respondent segments.

For example, one segment (an older, predominantly male population segment with higher home ownership level and lower income than the rest

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of the sample) was relatively insensitive to changes in bus fare and was influenced by changes in headway independent of changes in access distance. Another segment consisting of fewer registered voters with lower education also exhibited similar independent impacts of headway and access distance.

The technique is especially useful in reducing a large number of proposed alternative systems to a smaller set for further planning consideration by specifying the ranges within which variation of service characteristic would cause substantial changes in the intended usage responses.

INTRODUCTION

In order to plan successful bus operations, it is necessary to know what factors influence peoples' choices of buses for their travels. In particular, transit planners need to know potential users' travel habits and preferences and their sensitivities to varying levels of perceived service characteristics of a bus system.

If people's past travel behavior is not known, necessary information may be obtained either by experimentation or by simulation. Such information could be used for preliminary analysis of people's evaluations of alternative bus systems. Typically, experimentation is very expensive and hence is seldom adopted for preliminary evaluations. Simulation of mode-choices has been used extensively in travel demand studies. Reviewing the mode-choice literature over the last decade, Louviere, Beavers, Norman and Stetzer (1973) concluded that despite its widespread applications, simulation of mode choice models has not been able to accurately replicate individuals' mode choices. Consequently, Louviere et al recommended that future research should focus on simulating selective travel characteristics so as to predict mode choices more accurately. They also presented results of a study based on Andersons' Integration Theory (1971). The research reported herein is an attempt in this recommended direction, and proposes a simulation methodology to describe how individuals perceive changes in specific service characteristics. The proposed methodology involves a hypothetical situation in which a group of individuals are presented with various scenarios of bus operations using a home interview survey. Each scenario is characterized by a combination of three bus service characteristics, bus fare, headway and access distance. Information on the levels of the three service characteristics is presented to respondents who indicate their intentions to use buses for intra-urban travels if such a bus system were presently available. Statistical analysis of these intentions would indicate significance of the influences of the three service characteristics. Although intentions do not refer to individuals' commitment to use buses, the scenario approach employed in this research will provide transit planners with useful evaluations of alternative bus systems in terms of people's sensitivities toward their perceived levels of the three service characteristics.

The scenario approach used in this research is similar to the one used by Louviere et al (1973) with a group of students from the University of Iowa. The authors presented each student with a variety of bus operation scenarios specified by combinations of bus fare, access distance and headway. A 3x3x3 factorial design was adopted and the students' responses were analyzed using Analysis of Variance (ANOVA). The ANOVA results led Louviere et al to theorize alternative response functions and postulate the behavioral mechanism.

While Louviere et al investigated sensitivities of service characteristics of the total sample, this research seeks similar results for five distinct segments of individuals, each segment being homogeneous with respect to their general attitudes towards transportation. Such homogeneous segments were identified by Nicolaidis (1975) as part of a market segmentation study for public transportation.

The research reported herein postulates that people's preference for a bus system is based on their perceptions of specific service characteristics such as headway time, bus fare and access distance. This technique differs from the one devised by the authors (Nicolaidis and Krishnan, 1976) for analyzing people's intention under a different postulate. There the authors postulated that people would consider each bus operation scenario as a single stimulus and express their preference for a stimulus without explicity evaluating each service characteristic, as was done in this research.

The present technique differs in several ways from mode-choice modeling approaches reported in the literature for estimating relative influences of various factors on mode choice behavior (Brand, 1973). Firstly, mode choice models assume the existence of at least two alternatives to each individual. The proposed technique can be used to assess people's perceptions of a single bus system as well as several alternative systems. Secondly, mode choice models assume specific functional relationships between choice and independent variables. No specific relations

are assumed in the present technique. Thirdly, while mode choice models are developed primarily for forecasting purposes, the technique presented herein is used merely for testing significant influences of any or all service characteristics before undertaking the forecasting task.

DATA

The data used in this study were obtained from a random sample of 1804 households through a home interview survey administered in Orange County, California, by the Orange County Transit District (OCTD). The data were supplied by OCTD for purposes of developing and testing various transportation-oriented market research and planning methodologies.

The section of the survey which elicited respondents' intentions to use buses under various scenarios of bus operations is the main data source for this study. Fifty-four (54) scenarios, each characterized by a combination of bus fare, headway and distance from home to nearest bus station were presented to the respondents. These 54 combinations corresponded to six levels of bus fare (0, 25, 35, 50, 75 and 100 ¢), three levels of headway (15, 30 and 60 minutes) and three levels of distance from home to bus station (1, 3 and 5 blocks). Respondents were selected in such a way as to form six equal-sized groups, each group consisting of respondents who are located at a particular distance from home to an existing bus station. Each group responded to a different set of nine scenarios which were randomly selected from the 54 scenarios. The reason for selecting only nine out of 54 scenarios is to avoid possible response biases caused by fatigue or boredom from evaluating too many scenarios. A page from the questionnaire eliciting the intended bus usage is reproduced as Figure 1. The nine scenarios presented to each of the six groups are shown in Table 1.

METHODOLOGY

For each combination of bus fare, headway and distance from home to bus station (access distance), the respondents indicated the number of times out of ten that they would choose bus for all travels. It is hypothesized that the respondents' stated intentions could be expressed as the average response by all individuals plus main effects due to bus fare (B), headway (H) and access distance (D), and the interaction effects due to interplay of two or more factors. This hypothesis may be expressed as follows:

ANTICIPATED USAGE SECTION

NOW I'd like to ask you some questions about various bus rates and time schedules that might be offered. For each situation I read, tell me how many times out of ten trips you might ride the bus (SHOW CARD) to: work / school / do your shopping. Here's the first situation:

II-2 If there were a bus system that was free, ran 1 block from your home and destination every 30 minutes, how many times out of ten would you ride it?

0 1 2 3 4 5 6 7 8 9 10

II-8 If it were free, ran 5 blocks from your home and destination every 15 minutes, how many times out of ten would you ride it?

0 1 2 3 4 5 6 7 8 9 10

II-14 If it were 25¢, ran 3 blocks from your home and destination every 60 minutes, how often would you ride it?

0 1 2 3 4 5 6 7 8 9 10

II-20 If it were 35¢, ran 1 block from your home and destination every 30 minutes, how often would you ride it?

0 1 2 3 4 5 6 7 8 9 10

II-26 If it were 35¢, ran 5 blocks from your home and destination every 15 minutes, how often would you ride it?

0 1 2 3 4 5 6 7 8 9 10

Figure 1. A PAGE FROM THE QUESTIONNAIRE.

Table 1. Survey Design

BLOCKS FROM HOME TO BUS STATION DISTANCE, D	ACTUAL HOME TO BUS STATION DISTANCE IN BLOCKS																	
	1-3			4-7			8-11			12-15			16-20			21 OR MORE		
	HEADWAY TIME IN MINUTES, H																	
	(15)	(30)	(60)	(15)	(30)	(60)	(15)	(30)	(60)	(15)	(30)	(60)	(15)	(30)	(60)	(15)	(30)	(60)
1	B1	--	--	B1	--	--	--	--	B1	B2	--	--	--	B2	--	--	--	B2
3	--	B2	--	--	--	B2	B2	--	--	--	B1	--	--	--	B1	B1	--	--
5	--	--	B1	--	B1	--	--	B1	--	--	--	B2	B2	--	--	--	B2	--

BUS FARES : B1 = 0, 35 AND 75¢
B2 = 25, 50, AND 100¢

$$Y_{ijkm} = \mu + H_i + D_j + B_k + (HD)_{ij} + (DB)_{jk} + (HB)_{ik} + (HDB)_{ijk} + e_{ijkm} \quad (1)$$

where Y_{ijk} denotes intended bus usage of m th individual when the headway is at the ith level, the access distance at the jth level, and the bus fare at the kth level. The first term μ is the average response of all individuals. The terms H_i, D_j and B_k denote the three main effects when the factors are at the levels of their respective subscripts. The next three terms $(HD)_{ij}$, $(DB)_{jk}$, and $(HB)_{ik}$ denote the two-factor interaction terms while $(HDB)_{ijk}$ denotes the interaction effect of all three factors. The last term e_{ijk} is a random error term.

From the OCTD survey data, the interaction effects involving bus fare cannot be estimated since for any combination of the three service characteristics only one observation is recorded at each price level, as shown in Table 1. Therefore, in order to separate price effects from other effects shown in equation (1), both main and interaction effects involving bus fare are represented by a term called covariate, denoted by B which is linearly related to Y_{ijk}. A second covariate, X, is also included in the model so as to capture the influence of current distance between a respondent's home and the nearest bus station. The modified model is then

$$Y_{ijk} = \mu + H_i + D_j + (HD)_{ij} + \gamma B_{ijk} + \delta X_{ijk} + e_{ijk} \quad (2)$$

where B_{ijk} and X_{ijk} are the two covariates corresponding to the ith level of headway, jth level of access distance for the kth individual in the sample and γ and δ are coefficients of the two covariates.

The main and interaction effects as well as the coefficients γ and δ can be estimated by the least-squares technique which minimizes the sum of squares of the error terms. To test for significance of the main and interaction effects, the variance of a main or interaction effect is compared with the variance of the error term. If the ratio of the variances,

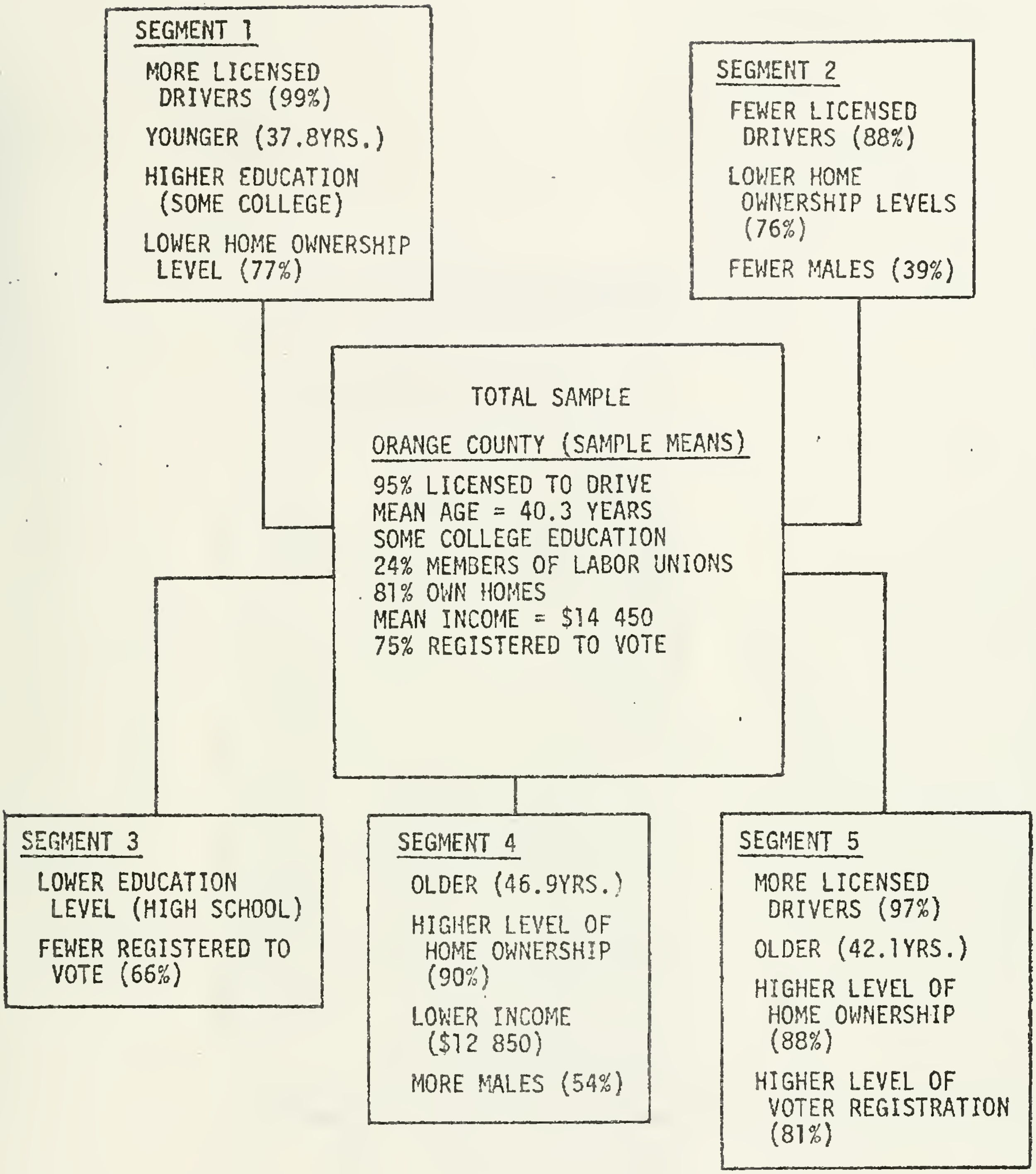

Figure 2. Difference among Segments - Socio-Economic Characteristics

Table 2. Average Intended Usage Responses

BUS FARE IN ¢ B	DISTANCE FROM HOME TO BUS STATION D								
	1 BLOCK			3 BLOCKS			5 BLOCKS		
	HEADWAY TIME IN MINUTES H'								
	(15)	(30)	(60)	(15)	(30)	(60)	(15)	(30)	(60)
0	6.17	6.21	5.32	5.76	5.27	4.86	4.69	4.04	2.82
25	5.50	5.43	4.22	4.82	3.63	3.63	3.63	3.36	2.44
35	4.58	4.64	3.56	4.34	3.52	3.27	3.54	2.74	2.14
50	3.54	3.30	2.50	2.65	2.16	2.37	2.38	2.24	1.66
75	2.12	2.27	1.72	2.03	1.80	1.78	1.94	1.49	1.34
100	1.69	1.73	1.40	1.47	1.40	1.42	1.52	1.38	1.26

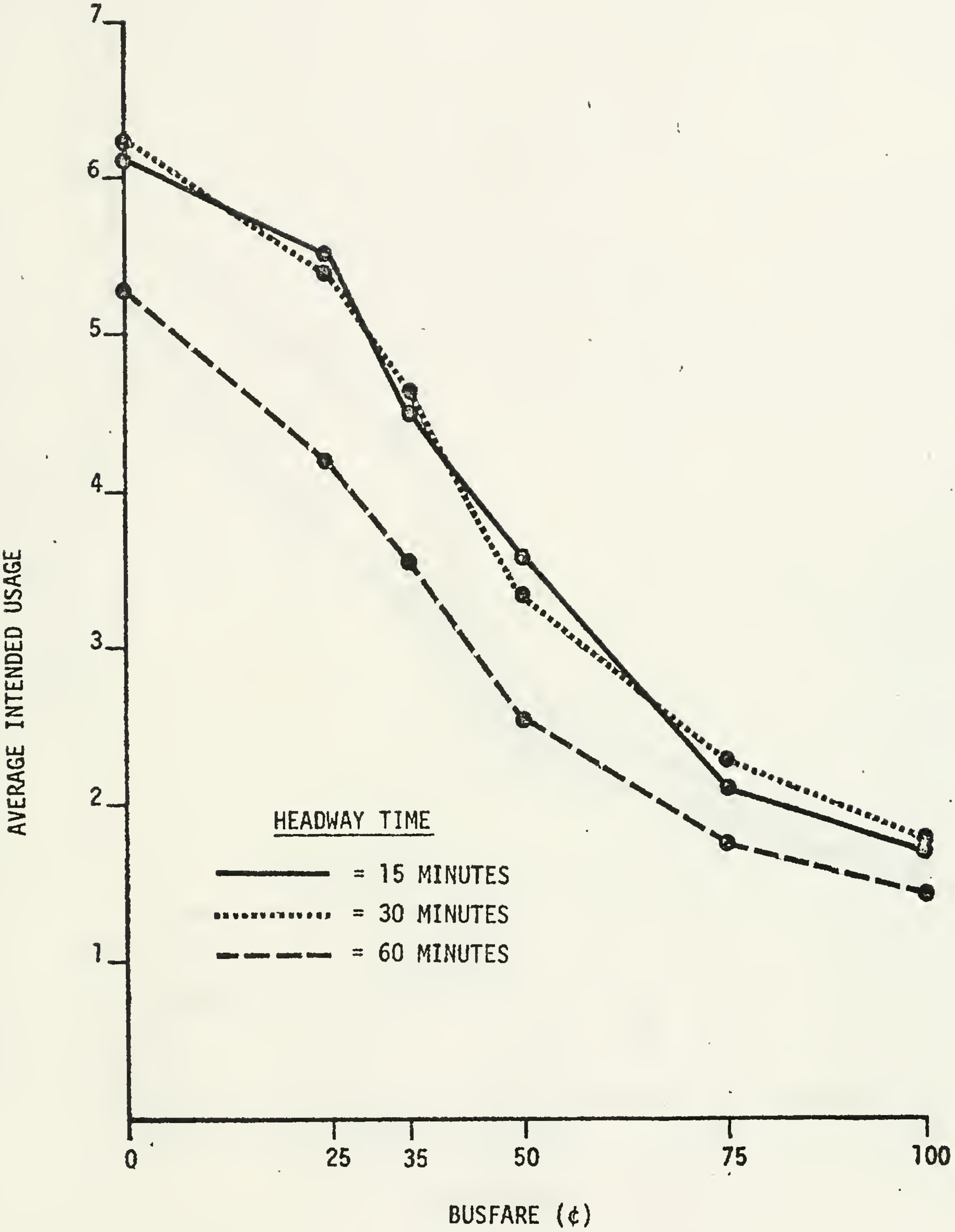

Figure 3. Average Intended Usage - Access Distance of 1 Block

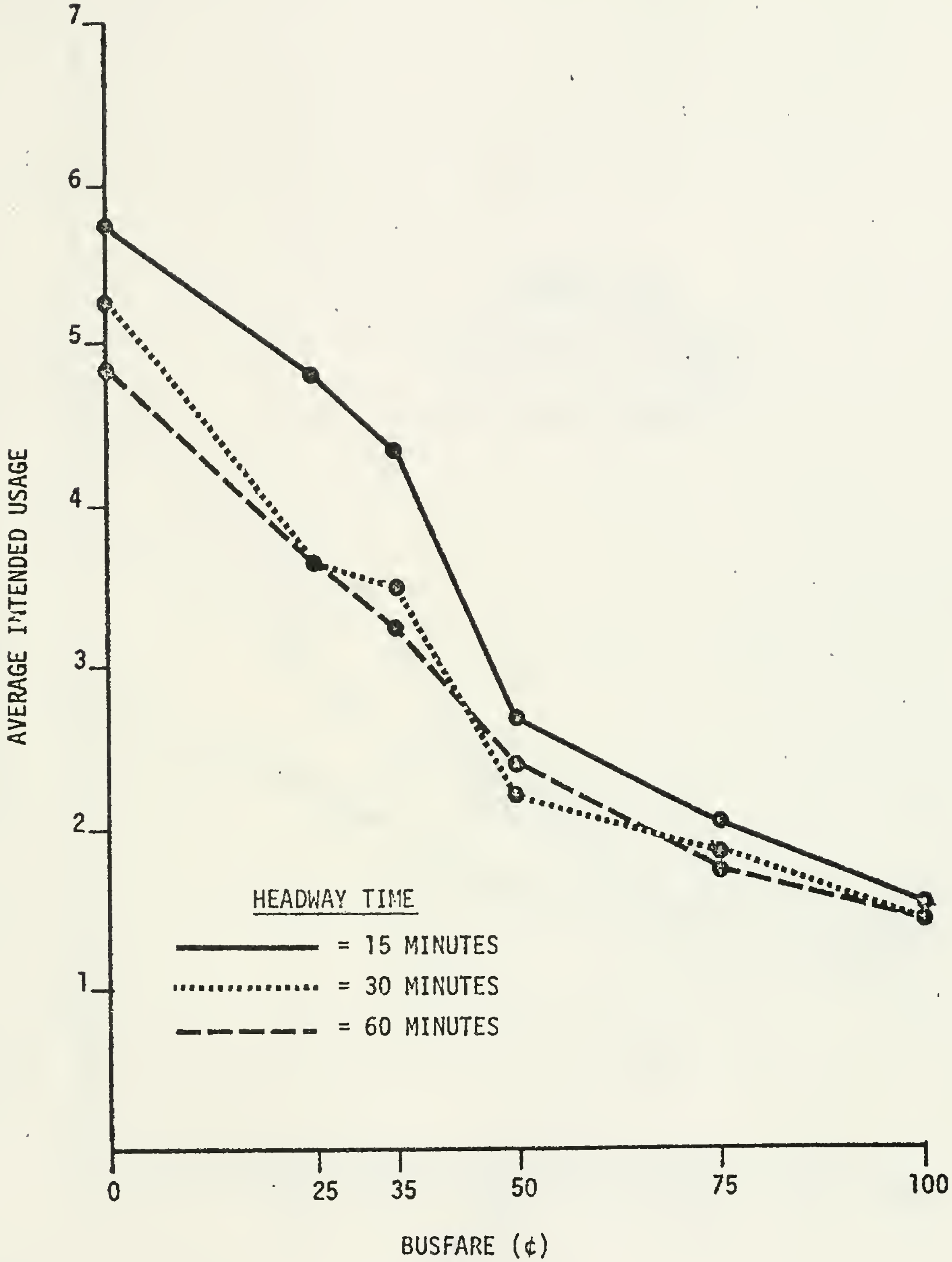

Figure 4. Average Intended Usage - Access Distance of 3 Blocks

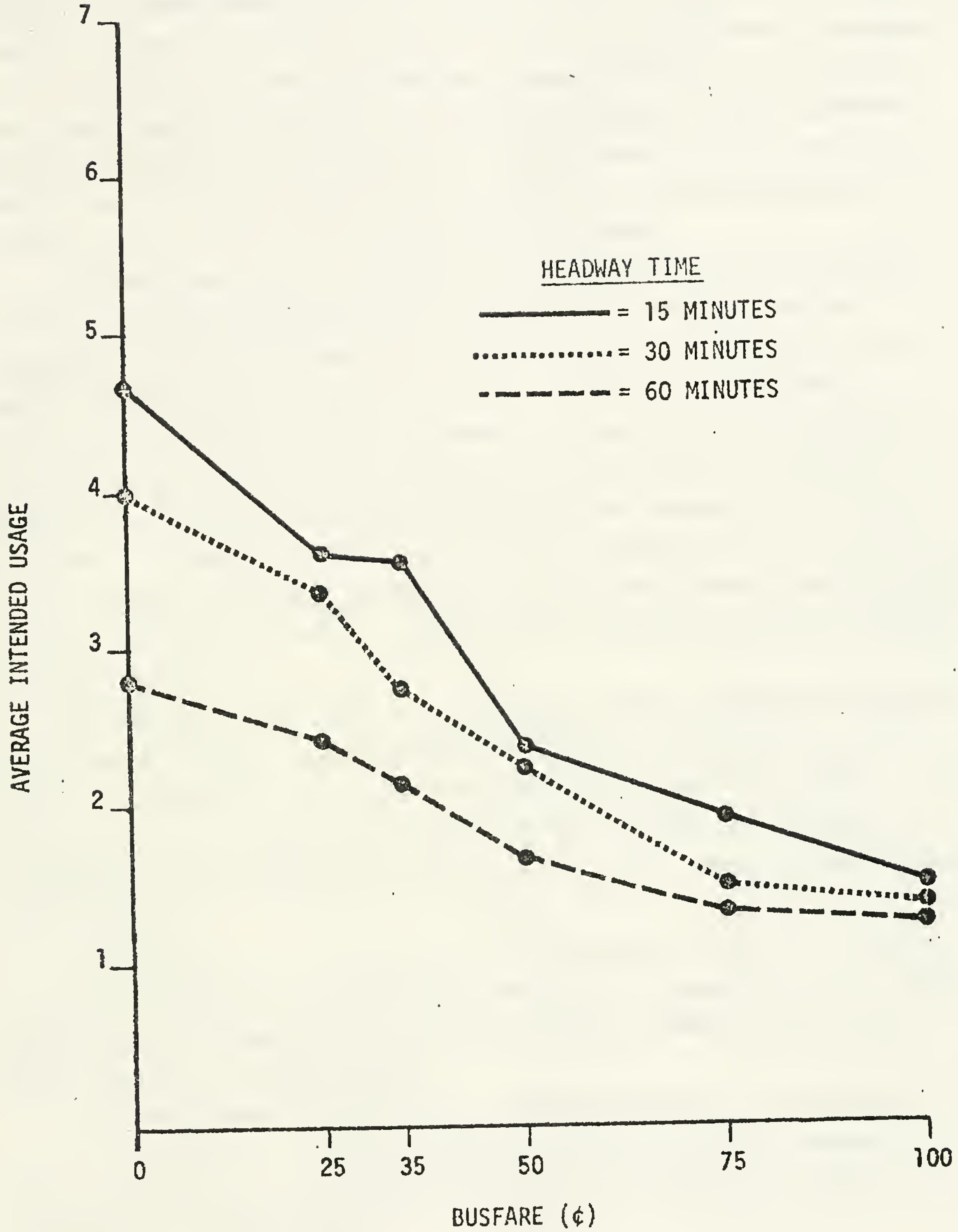

Figure 5. Average Intended Usage - Access Distance of 5 Blocks

distance is one block, people are indifferent to headways of 15 and 30 minutes. Similar examinations of Figures 4 and 5 suggest that when the access distance is three blocks, people would be indifferent to headways of 30 and 60 minutes and that when the access distance is five blocks, they would respond differently to different headways. These apparently dissimilar response patterns lead to the hypothesis that the main as well as the interaction effects of the three service characteristics are significant. The hypothesis is tested using ANCOVA.

The ANCOVA was first employed on the total sample taking bus fare and current distance between home and the nearest bus stop as two covariates. The ANCOVA results in Table 3 showed that for the entire sample varying levels of access distance and headway significantly influenced the intended usage responses. In particular, both main and interaction effects of the two factors were statistically significant at 0.05 level, confirming hypotheses generated from inspection of Figures 3, 4 and 5. Since the coefficients of two covariates were also significant, it was concluded that bus fare and current distance significantly influenced the intended usage response. These results coincide with those obtained by Louviere et al.

ANCOVA results for each of the five homogeneous segments are shown in Tables 4 through 8 and summarized in Table 9. Significance of the main and interaction effects is tested by F-values shown in these tables. The last column indicates the level at which the F-value is significant; "NOT SIGNIFICANT" indicates that the F-value is insignificant at 5% level.

In segments 1, 2 and 5, the main and interaction effects of headway and access distance are significant. However, in segments 3 and 4, only the main effects are significant; the interaction between headway and access distance is insignificant.

The coefficients of bus fare and current distance are significant in all but segment 4. Both covariates are insignificant in segment 4, which consists of older, predominantly male population with higher home ownership and lower income.

Table 3. Analysis of Covariance for Total Sample

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F	SIGNIFICANCE
BUS FARE	1	24369·26	24369·26	2846·88	.001
ACTUAL DISTANCE	1	35·91	35·91	4·20	.001
HEADWAY	2	1822·06	911·03	106·43	.001
ACCESS DISTANCE	2	3810·75	1905·38	222·59	.001
HEADWAY x ACCESS DISTANCE	4	313·25	156·62	18·30	.001
ERROR	16225	138966·38	8·56	-------	----
TOTAL	16235	169317·61	--------	-------	----

Table 4. Analysis of Covariance, Segment 1

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F	SIGNIFICANCE
BUS FARE	1	7072·59	7072·59	882·97	.001
ACTUAL DISTANCE	1	1·53	1·53	0·19	NOT SIGNIFICANT
HEADWAY	2	408·75	204·38	25·52	.001
ACCESS DISTANCE	2	908·37	454·18	56·70	.001
HEADWAY x ACCESS DISTANCE	4	255·31	63 · 83	7·97	.001
ERROR	4534	36310·57	8·01	------	----
TOTAL	4544	44957·12	-------	------	----

Table 5. Analysis of Covariance, Segment 2

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F	SIGNIFICANCE
BUS FARE	1	8424·12	8424·12	850·06	.001
ACTUAL DISTANCE	1	24·84	24·84	2·51	NOT SIGNIFICANT
HEADWAY	2	586·78	293·39	29·61	.001
ACCESS DISTANCE	2	1332·23	666·12	67·22	.001
HEADWAY x ACCESS DISTANCE	4	61·36	15·34	1·55	NOT SIGNIFICANT
ERROR	3490	34597·68	9·91	------	----
TOTAL	3500	45027·01	-------	------	----

Table 6. Analysis of Covariance, Segment 3

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F	SIGNIFICANCE
BUS FARE	1	3464·62	3464·62	490·05	.001
ACTUAL DISTANCE	1	35·56	35·56	5·03	.05
HEADWAY	2	227·34	113·67	16·08	.001
ACCESS DISTANCE	2	515·75	207·88	29·40	.001
HEADWAY x ACCESS DISTANCE	4	31·61	7·90	1·12	NOT SIGNIFICANT
ERROR	2851	20200·28	7·07	------	----
TOTAL	2861	24475·15	-------	------	----

Table 7. Analysis of Covariance, Segment 4

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F	SIGNIFICANCE
BUS FARE	1	2273·04	2273·04	276·09	.001
ACTUAL DISTANCE	1	108·66	108·66	13·20	.001
HEADWAY	2	186·44	93·22	11·32	.001
ACCESS DISTANCE	2	375·52	187·76	22·81	.001
HEADWAY x ACCESS DISTANCE	4	25·87	6·47	0·79	NOT SIGNIFICANT
ERROR	2050	16877·50	8·23	------	----
TOTAL	2060	19847·03	-------	------	----

Table 8. Analysis of Covariance, Segment 5

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F	SIGNIFICANCE
BUS FARE	1	3662·11	3662·11	428·00	.001
ACTUAL DISTANCE	1	16·18	16·18	1·89	NOT SIGNIFICANT
HEADWAY	2	475·88	237·94	27·81	.001
ACCESS DISTANCE	2	773·12	386 56	45·18	.001
HEADWAY x ACCESS DISTANCE	4	72·08	18·02	2·11	NOT SIGNIFICANT
ERROR	3256	27859·60	8·56	------	----
TOTAL	3266	---------	-------	------	----

Table 9. Summary of ANCOVA Results

	SOCIOECONOMIC CHARACTERISTICS	HEADWAY	ACCESS DISTANCE	INTERACTION	COVARIATES	
					BUS FARE	CURRENT ACCESS DISTANCE
TOTAL SAMPLE	95% LICENSED DRIVERS AVERAGE AGE : 40.3 YEARS SOME COLLEGE EDUCATION 24% MEMBERS OF LABC.. UNIONS 81% HOME OWNERS MEDIAN INCOME, $14 450 75% REGISTERED VOTERS	*	*	*	*	*
SEGMENT 1	MORE LICENSED DRIVERS YOUNGER HIGHER EDUCATION LOWER HOME OWNERSHIP	*	*	*	*	*
SEGMENT 2	FEWER LICENSED DRIVERS LOWER HOME OWNERSHIP FEWER MALES	*	*	*	*	*
SEGMENT 3	LOWER EDUCATION FEWER REGISTERED TO VOTE	*	*		*	*
SEGMENT 4	OLDER HIGHER HOME OWNERSHIP LOWER INCOME MORE MALES	*	*			*
SEGMENT 5	MORE LICENSED DRIVERS OLDER HIGHER HOME OWNERSHIP MORE REGISTERED TO VOTE	*	*	*	*	*

*: INDICATES SIGNIFICANCE AT THE 5% LEVEL

DISCUSSION

The Analysis of Covariance tests show that changes in bus fare, headway time and access distance significantly affect individuals' intended usage of bus. However, intended usage is relatively insensitive to the three service characteristics when they are already at extreme high or extreme low levels. For example, a change in bus fare from 0 to 25 cents did not produce as much decline in the usage response as an increase from 25 cents to 35 cents. The latter increase in bus fare, however, produced a larger decline in the usage response than an increase from 75 cents to one dollar. These results lend evidence to the existence of lower and upper threshold points corresponding to each service characteristic and to the hypothesis that individuals' responses are sensitive to the levels of the service characteristics only when they vary between these upper and lower threshold points.

Two of the five segments yielded insignificant interaction between headway time and access distance. The absence of the interaction can be interpreted to mean that headway time and access distance influence intended usage response in a linear compensatory manner. In other words, disutilities resulting from increases in the level of one service characteristic can be offset by utilities gained from decreases in the level of the other service characteristic. One of the two segments which yielded no interaction effect is the older, predominantly male segment, which is also characterized by higher home ownership and lower income. The other segment consists of fewer registered voters with lower education.

The approach used in this research is not viewed as a forecasting tool for planning purposes. Rather, it is seen as an explanatory tool for identifying the variables which influence transit usage, and the ranges of the variables at which the influence is maximum. The approach allows the analyst not only to assess people's sensitivities to three service characteristics but also to identify segments of the sample which exhibit different sensitivity structures. This knowledge can lead to the formulation and structuring of travel demand models which would include appropriate causal variables and account for interactions among these variables. This can be potentially useful for designing transportation systems which will provide service to different segments of population.

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