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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
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INITIAL RESULTS BASED ON A SOUTHERN CALIFORNIA
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ABSTRACT

This paper presents a statistical analysis of commuters' route choice behavior and the influence of traffic information. The analysis is based on a 1992 computer-aided telephone interview survey of Los Angeles area morning commuters. Cross tabulations were performed on the data to explore interrelationships among variables and provide a basis for subsequent model estimation. The results showed that only 15.5% of the respondents reported that they don't always follow the same exact route to work, which indicates the potential benefit from an information system that would make more commuters aware of alternative routes. Surface streets are heavily used as secondary routes, indicating how frequently diversion of traffic to surface arterials is already occurring, perhaps in an inefficient way. Real-time, in-vehicle route guidance may provide access to more efficient secondary routes. About 36.5% of the respondents listen to traffic reports before leaving their homes, and 51.2% listen while driving. In general 60.1% listen to reports at home and/or en-route. Two sets of models were estimated: bivariate probit models of whether individuals follow the same route to work everyday and whether they receive traffic information (en-route), and negative binomial models of the frequency of route changes per month based on pre-trip and en-route traffic reports. The estimation results underscore the important relationship between the use of traffic information and the propensity to change routes. In addition, important relationships are uncovered relating the influence that commuters' socioeconomic characteristics and the level of traffic congestion they face have on traffic information use and route change frequency. The results' important implications for advanced traveler information system (ATIS) development are discussed in the paper.

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1. INTRODUCTION

The problem of route choice for a commute trip could be defined as follows: given the characteristics of the trip (e.g. departure or **arrival** time, origin, destination) choose the best route through the transportation network in terms of some criterion or criteria. This best route most often is thought of as the one which **minimizes** travel disutility (e.g. travel time, distance, or generalized travel cost). In reality, the problem of route choice faced by an automobile driver is very complex because of the very large number of possible alternative routes through the road networks, and the complex patterns of overlap between the various route alternatives [1].

In an ongoing Partners for Advanced Transit and Highways (PATH) project at UC Davis, ATIS Impact on Travel Demand, a variety of issues regarding traveler response to information are being investigated (see for example Vaughn, et al. [2,3]; Yang, et al. [4]; Abdel-Aty et al. [5]). These earlier papers focused on development of learning models of drivers adaption to traffic advice, particularly when the advice is not always correct. A second part of the project deals with studying the actual route choices of drivers, with the objective of developing refined route choice models that *can* include the effect of traveler information. This paper is concerned with the second part of the project.

To probe into drivers' route choice behavior, a telephone survey of Los Angeles **area** morning commuters was conducted **as** part of the project. The survey was designed to investigate how much information drivers have about their routes, their awareness of alternate routes, their awareness of traffic conditions which could affect their route choices, and their use of available traffic information either en-route or pre-trip or both. The survey, undertaken in May and June, 1992, is differentiated from previous studies in that the specific routes taken by individuals were obtained for their morning commute. In addition to the reported analyses of route choice behavior, the specific routings will be used in subsequent studies to understand choice behavior on real routes.

This paper describes the survey design and administration. General descriptive statistics are also introduced to show the characteristics, preferences and perceptions in commuters' route choice

behavior. Models of traffic information use and the propensity to use alternative routes are also developed. Bivariate probit models were chosen to describe each commuter's use of traffic information and alternative routes. In addition, negative binomial models are used to assess frequency of commuters' route changes based on traffic reports, and route and individual characteristics. Further details regarding the survey itself and additional descriptive statistics are contained in a project report [6].

2. LITERATURE REVIEW

Surveys have been used in several studies with the aim of determining respondents' route choice behavior (Khattak et al., 1991 [7]; Hatcher and Mahmassani, 1992 [8]; Haselkorn et al., 1990 and 1991 [9,10]). Table 1 summarizes and compares these studies.

Khattak [7] used mail-back questionnaires to evaluate the effect of traffic reports on Downtown Chicago commuters' route and departure time changes. Questionnaires were distributed at parking facilities to more than 2000 commuters, of whom 700 responded. The survey focused on the effect of attributes of the traffic information system, attributes of alternative routes, and the individual and situational factors on decisions to change route and/or departure time. Automobile commuters were found to use traffic information more while en-route than while planning their trips. Drivers were more likely to switch routes if they could get traffic information whenever they need it, and, among socioeconomic attributes, higher income drivers and males were more likely to take alternate routes.

Hatcher and Mahmassani [8] observed route and trip scheduling decisions for evening commuters using a two stage mail survey. A short screening survey was sent to 3000 randomly selected households in Austin, Texas, yielding 624 responses. A second stage survey sent to 331 selected first phase respondents consisted of detailed diaries of actual departure times, route description, and intermediate stops for the morning and the evening commuting trips for each day of a two-week period. In addition the survey asked for the official work starting and ending times and target arrival time at home for the evening commute. This information was gathered to measure daily commute time, schedule delay (the time between scheduled work start time and a

Table 1: Summary of Route Choice Surveys' Studies

Study	Sample	Methodology	Objectives	Findings
1	Down town Chicago automobile commuters	Mail-back questionnaires distributed at parking facilities. Yielded 700 completed surveys	Evaluate the effect of traffic reports on down town Chicago commuters' route and departure time changes	Traffic reports are used en-route more than pretrip, drivers are more likely to switch routes if they could get traffic information whenever they need it, and higher income and male drivers were more likely to take alternate routes
2	Random commuters sample in Austin, Texas	1. Short one page mail survey. Yielded 624 responses. 2. Travel diaries. 331 responses	Observe route and trip scheduling decisions for evening commuters	Commuters tend to change departure times more frequently than routes. Travelers with long trips may face too much uncertainty with regard to travel time variability. Work place variables (e.g. lateness tolerance) dominate evening departure time, route and switching behavior. No clear cut effect of socioeconomic variables.
3	commuters who use a specific freeway corridor Washington state	1. Mail-back survey, distributed on-road. Yielded 3,893 responses. 2. In-person survey. Questioned specifically on ATIS technologies to 100 subjects.	Gather information about motorist activities and behaviors, particularly the potential for changing these behaviors through the design and delivery of information.	Commuters could be divided into four groups: route changers, non-changers, route and time changers, and pre-trip changers. When exposed to potential ATIS screens 55% of those identified as nonchangers indicated a willingness to change route.

Note: The studies cited in this table are:

1. Khattak, Schofer and Koppelman [7]
2. Hatcher and Mahmassani [8]
3. Haselkom, Spyridakis and Barfield [9,10]

commuter's preferred arrival time), and departure time switching. A total of 164 participants completed at least three days of the diary. It was found that commuters tend to change departure times more frequently than routes. Also, it was found that travelers with short trips may see no need for altering routes (small absolute time savings), while those with long trips may face too much uncertainty with regard to travel time variability to distinguish one route's superiority over another. Socioeconomic variables such as gender, age and home ownership, didn't have a clear-cut effect.

Haselkorn [9,10] utilized a large scale, on road, mail-back survey which targeted a specific freeway corridor in the state of Washington. The aim of the study was to make recommendations for the improvement, development and design of ATIS systems. Nearly 10,000 commuters from the selected freeway corridor were surveyed. With a response rate of approximately 40% , **3,893** commuters responded to the survey and 100 of them participated in a follow-up, in-person survey. Cluster analysis was used to separate the subjects into four major driver groups by characterizing the effect of traffic information on departure time, route choice and mode choice: Route Changers, Non-Changers, Route and Time Changers, and Pre-Trip Changers. Route changers, identified as willing to change route but unwilling to change departure time or transportation mode, made up 20.6% of the sample. Non-changers were unwilling to change departure time, route, or transportation mode and made up 23.4% of the sample. Route and time changers were willing to change route and departure time but not transportation mode and made up 40.1% of the sample. Pre-trip changers were willing to change time, route or mode and made up 15.9% of the sample. Abdel-Aty, et al. [11] summarizes and compares the modeling techniques and conclusions of the previous studies.

All the above mentioned studies used the mail survey design in one way or another. Mail surveys, in general, yield low response rates, do not provide interaction between the interviewer and the respondent, and usually require substantial time for organization and administration. Very few surveys, however, have addressed route choice behavior, perceptions, and decision mechanisms of commuters, and examined the exact routes taken by the drivers. **This** study is an attempt to gain a better understanding of drivers' route choice behavior through a survey which collects detailed information on the exact commute routes, and the factors that affect route choice.

3. ROUTE CHOICE SURVEY

A route choice survey was developed targeting Los Angeles area morning commuters. A mail-out/mail-back survey instrument was initially designed to gather detailed information on commuters' main and alternate routes, to determine the level of information commuters have about these routes, to measure commuters' attitudes toward, and perceptions of, these routes,

and to determine how existing traffic information affects their route choice behavior. The mail survey instrument required several branchings, increasing its level of complexity, potentially jeopardizing the response rate and response accuracy. Therefore, it was decided to **perform** a computer-aided telephone interview (CATI) survey. A CATI survey allows interviewer/respondent interaction and automatically handles branchings with complete reliability and lower interviewer error. It is also believed to yield a higher response rate.

The CATI Survey

The survey targeted a random sample of adult commuters residing in the area covered by the South Coast Air Quality Management District, which includes most of the contiguously populated areas of Los Angeles, Orange, San Bernardino and Riverside Counties. The sampling, based on a Mitofsky-Waksberg cluster sampling design [12], covered both listed and unlisted numbers. The Mitofsky-Waksberg sampling reduces the number of unproductive dialings, and improves efficiency [13].

The Survey Content

The following information was obtained from each respondent:

- Identification of the specific primary commute route by segment (each different road/freeway in sequence for the whole commute route).
- Availability of alternate commute routes, and identification of the secondary route by segment.
- Detailed information on both primary and secondary routes, including perceived traffic conditions.
- Individual's perception of the severity of different **types** of delays and other problems.
- Information that the respondent receives before and during the commute, and its effect on **his** behavior and awareness **of** the highway/street network.
- Demographic and socioeconomic data, including household income, gender, employment status, and education level.

4. DESCRIPTION OF THE SAMPLE

In all, 944 commuters were surveyed, in May and early June 1992. Summary statistics for the sample are presented in Table 2.

Table 2: Sample summary statistics (averages unless noted)

● Commute distance on usual route (miles)	12.75
● Travel time on usual route (minutes)	28.14
● Trip duration (including stops)	31.9
● Percent of respondents commuting in single-occupant autos/carpool/public transit	78.8/14.6/4.9
● Percent receiving pre-trip traffic reports	36.5
● Percent receiving en-route traffic reports	51.25
● Percent of respondents with flexible/somewhat flexible/ fixed work starting time	24.4/30.4/45.2
● Percent male/female	51.3/48.7
● No. of household cars	2.31
● No. of years at present address	7.24
● No. of years at present job location	5.52
● Percent own/rent their homes	59/41
● Household income	38,750
● Percent of college graduates	43.8
● Think traffic congestion is a problem or major problem (percent)	61.3
● Think trip time uncertainty is a problem or major problem (percent)	31.9

To test the representativeness of the sample, several socioeconomic and commute characteristics were compared **to**, and statistically tested with, the 1990 Census [14], the 1991 California Statewide Travel Survey results (CSTS) [15], and the 1990 California Statistical Abstract [16]. In most cases the null hypothesis that the values from the route choice survey are not different from the corresponding statistical sources was not rejected at the 0.05 level of significance, implying that the sample **is** representative of the population in the study **area** (among the variables tested with the **three** cited data bases are: Income, mode split, home ownership, gender, across the four counties). Tables 3 and 4 show examples of the comparisons performed for income and mode split.

Table 3: Average Household Income for the Sample, California Statewide Travel Survey, California Statistical Abstract, and Median Income for the 1990 Census.

County	Average Income			Median Income
	Survey	CA Statewide Travel Survey 1991 using only study area residents	CA Statistical Abstract (1990)	Census (1990)
Los Angeles	32,500	32,750	38,138	34,965
Orange	43,250	40,655	36,151	45,922
San Bernardino/ Riverside	33,500	28,805	35,004	33,081
Overall Sample	38,750			

Statistical tests

Using t-statistics to test the null hypothesis that the mean income for each county is not different from the corresponding value in CA statewide Survey (CSTS), and CA statistical Abstract (CASA)

Los Angeles County

CSTS $t = -0.01$ $df = 592$ Hypothesis **not** rejected at 0.05
level of significance

CASA $t = -0.24$ $df = 592$ Hypothesis not rejected

Orange County

CSTS $t = 0.11$ $df = 150$ Hypothesis not rejected

CASA $t = 0.30$ $df = 150$ Hypothesis not rejected

San Bernardino/Riverside Counties

CSTS $t = 0.20$ $df = 42$ Hypothesis not rejected

CASA $t = -0.06$ $df = 42$ Hypothesis not rejected

Table 4: Comparison of Sample Mode Share with 1990 Census.

county	Percent of Drive alone, Carpool and Public Transit Users					
	Drive Alone	Survey Carpool	Public Transit	Drive Alone	census 1990 Carpool	Public Transit
Los Angeles	79.1	15.2	5.7	85.6	15.5	6.5
Orange	83.2	14.9	1.8	90.4	13.7	2.5
San Bernardino/ Riverside	82.2	15.6	2.2	91.8	17.3	0.8

Note: Totals add up to more than 100% in the 1990 Census because it account for multiple modes users. Statistically testing if the percent of carpoolers is not different from expected values from the 1990 census, is not rejected.

5. COMMUTE CHARACTERISTICS

Trip durations (usual travel time including stops) are low. About 28.3% of the trips are between 10 and 20 minutes and 19.7% are between 20 and 30 minutes, but only 7.4% are more than one hour. To compare the distribution of the trip durations for the sample with four county data from the California Statewide Travel Survey (CSTS) data, the travel time in the CSTS data was calculated by taking the difference between the trip ending time and the AM trip beginning time, for trips that start at home and end at work, for heads of households who live in the study area. The distribution is illustrated in Table 5. Using a Chi-square test, the null hypothesis, that the normal trip durations in the sample are not different from the expected values from the California statewide travel survey, is rejected at the 0.05 level of significance ($\chi^2 = 139.88$, $df = 12$). However, the distribution is very close to the distribution of the sample. About 30.8% of the trips are between 10 and 20 minutes, 22.7% are between 20 and 30 minutes, and 5% are more than one hour.

Table 5: Comparison of the distribution of the morning commute time for the sample and CSTS

Commute Time (minutes)	Route Choice Survey (percent)	California Statewide Travel Survey (percent) (using only study area residents)
≤ 10	11.2	18.7
> 10 - 20	28.3	30.8
> 20 - 30	19.7	22.7
> 30 - 40	14.4	10.8
> 40 - 50	11.9	7.0
> 50 - 60	7.1	5.0
> 60 - 70	0.9	1.5
> 70 - 80	3.0	2.2
> 80 - 90	1.2	0.2
> 90 - 100	0.7	0.2
> 100 - 110	0.5	0.2
> 110 - 120	0.6	0.0
> 120	0.5	0.7

Comparing the distribution of longest driving time experienced during the previous two weeks with the usual driving time, indicated considerable travel time variation. The majority of the respondents (55%) reported between 4 and 20 minutes difference. This was not the case in the distribution of the shortest driving time experienced when compared to usual driving time, since the majority (69%) of the respondents reported differences below 8 minutes. However, these distributions show a considerable fluctuation in travel times.

The mean driving time for the sample is 28.1 minutes, and for the SCAG area it is 27 minutes [15] (SCAG covers the four targeted counties in addition to Ventura county). Using a t-test, the null hypothesis, that the mean of the usual driving time for the sample is not different from the mean commute travel time in the Statewide Travel Survey data, was not rejected at the 0.05 level of significance ($t=0.06$, $df=890$).

The distribution of the trip distances indicated that a large percent of the trips are short distance commute; i.e. 24.4% of the trips are less than 4 miles, and 21.7% are between 4 and 8 miles. Only 5 respondents had a trip more than 60 miles. The mean distance is 12.75 miles.

Traffic Information Use

Traffic information questions were divided into two groups depending on where the information is received, either before (pre-trip information) or while driving (en-route information) to work. About 36.5% of the respondents listen to traffic reports before leaving their homes, and 51.25% listen while driving. Close to 27.6% of the respondents listen to traffic reports both at home and en-route, and 60.1% listen to reports either at home or en-route, while 39.9% never listen to reports. These findings are consistent to a great extent with Khattak [7]. Most respondents who receive traffic information perceive traffic reports to be either very accurate or somewhat accurate. Figure 1 depicts the respondents' perception of the accuracy of the traffic reports they receive.

Commuters indicating that they sometimes receive traffic information tend to receive these reports every day. Almost 64% of respondents listening to reports before leaving home; 55%

of respondents listening while driving, indicated that they receive reports every day, or nearly every day (Figure 2).

More females listen to traffic reports before leaving home to work than males (171 out of **426** vs. **152** out of **459** respectively), while more males listen to reports en-route than females (250 out of **459** vs. **203** out of **425** respectively). The hypothesis of independence was rejected using Pearson chi square at a 0.05 level of significance. It was also found that more females change their route or departure times as a result of listening to traffic reports before leaving their homes (Figures **3** and **4**), while men changed their route more frequently than females as a result of traffic reports they hear while driving to work (Figure 5). Possibly socioeconomic and/or commute characteristics associated with gender led to the previous finding, which is that females tend to prefer pre-trip information, while males tend to prefer en-route information.

As mentioned before, **323** respondents (**36.5%** of **885** who answered this question) listen to traffic reports before leaving home. Of these, about 5% often change their departure time, **36.1%** sometimes change it, and the rest never change their departure time.

It was **also** found that respondents who stated that traffic conditions on their usual route are bad or very bad, or that there are substantial differences in traffic from day to day, reported that they listen to traffic information before leaving and while driving, more than respondents who indicated that traffic conditions are good or very good, or that traffic conditions are about the same every day. Again the hypothesis of independence between traffic conditions and listening to reports was rejected at the 0.05 level. Evidently those commuters who perceive a large variation in their traffic conditions, or that traffic conditions are bad on their routes, **try** to find out more about these conditions by listening to traffic reports.

Commuters who use freeways may be more likely to receive traffic information if their freeway traffic conditions are perceived as heavy or very heavy. **The** relation was confirmed using chi square test for pre-trip information, but not found for en-route information, indicating that commuters plan for using freeways **ahead**, i.e. **try** to **find** out their freeway(s) conditions in advance, possibly because these are the segments of their route that are exposed most to delays.

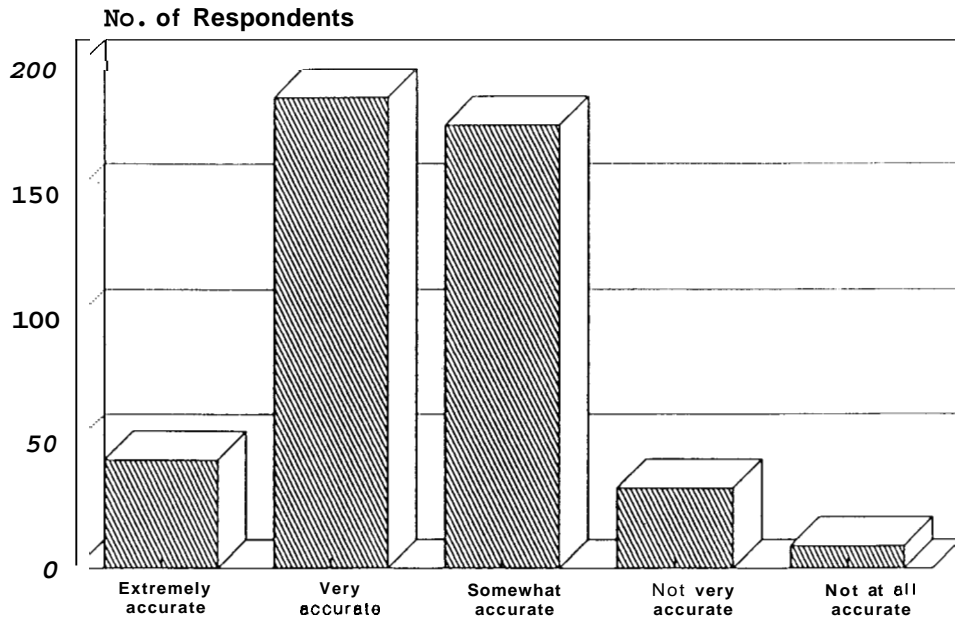


Figure 1: Commuters' perception of the accuracy of traffic reports

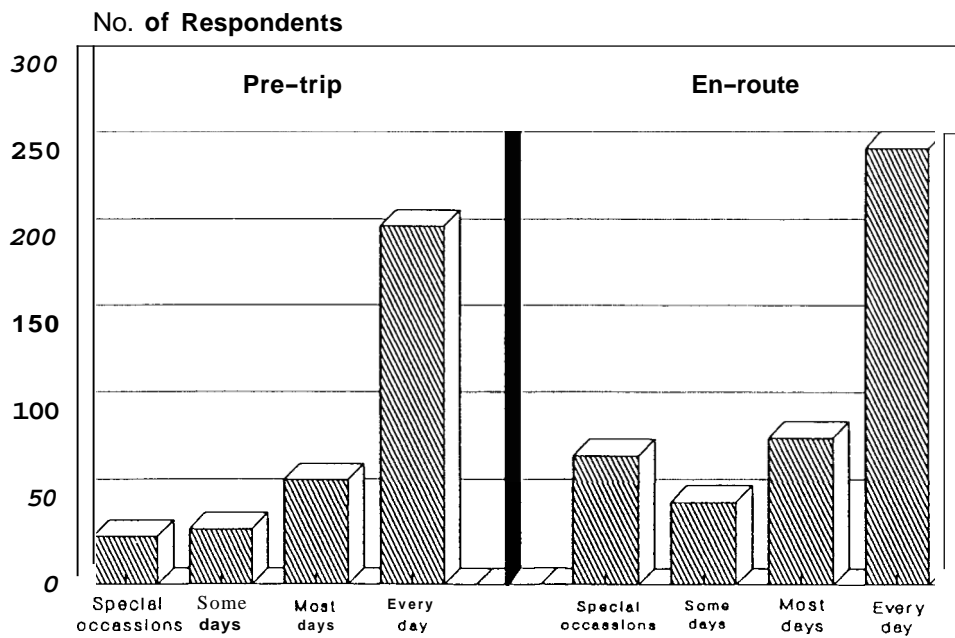


Figure 2: Frequency of listening to traffic reports

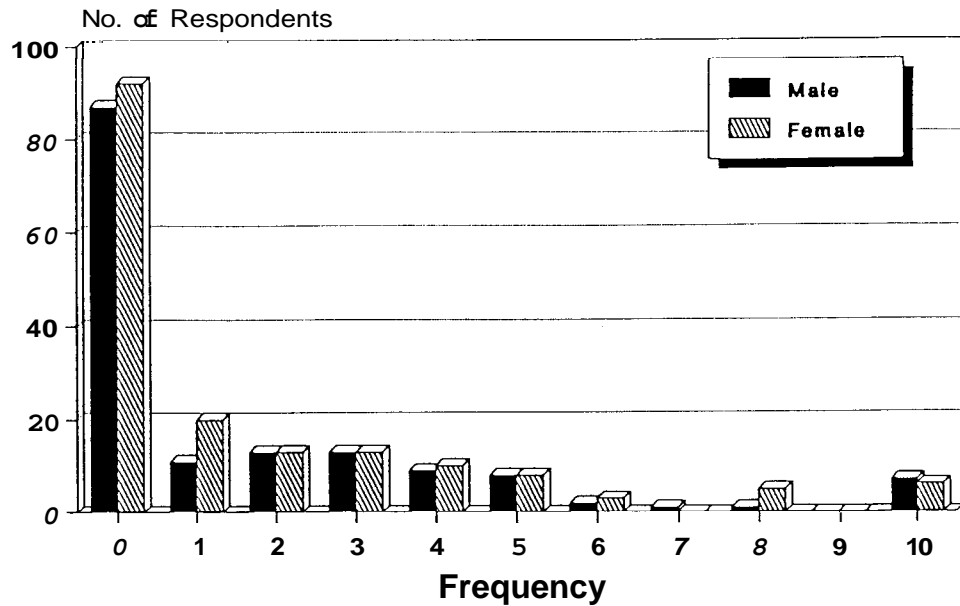


Figure 3: Frequency of changing routes per month based on pretrip traffic information (322 respondents)

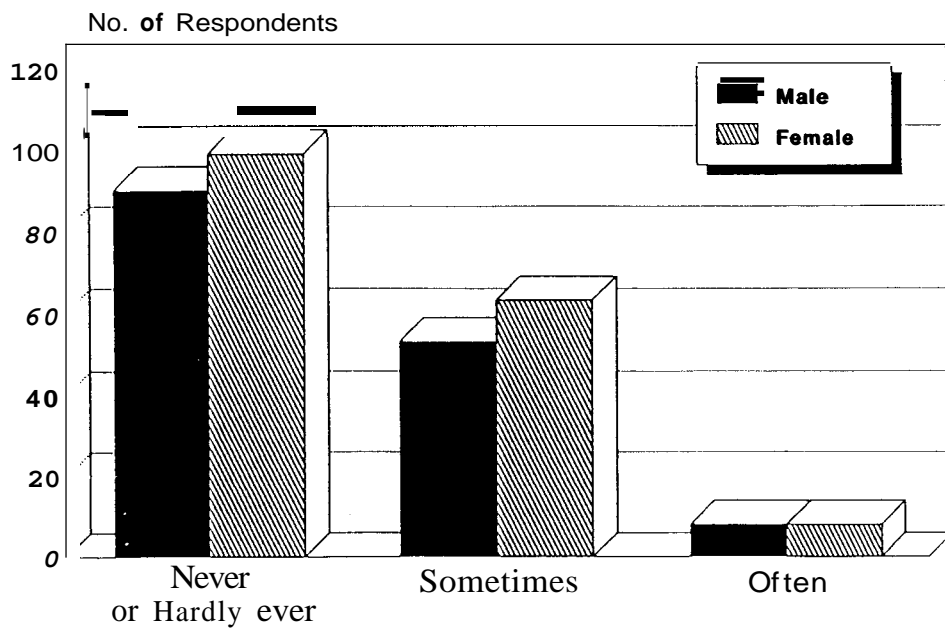


Figure 4: Departure time changes based on pretrip traffic reports (321 respondents)

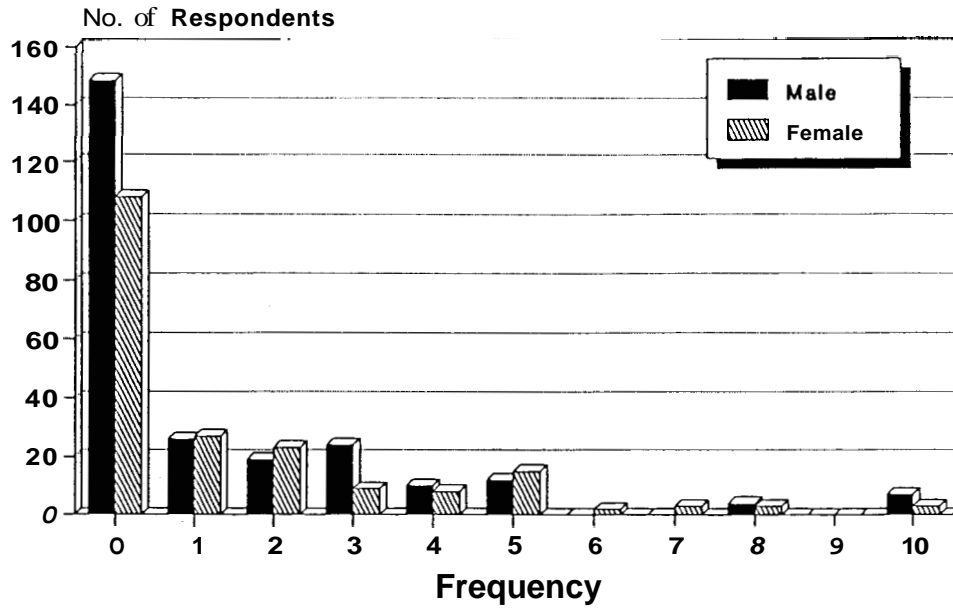


Figure 5: Frequency of changing routes per month based on en-route traffic information (451 respondents)

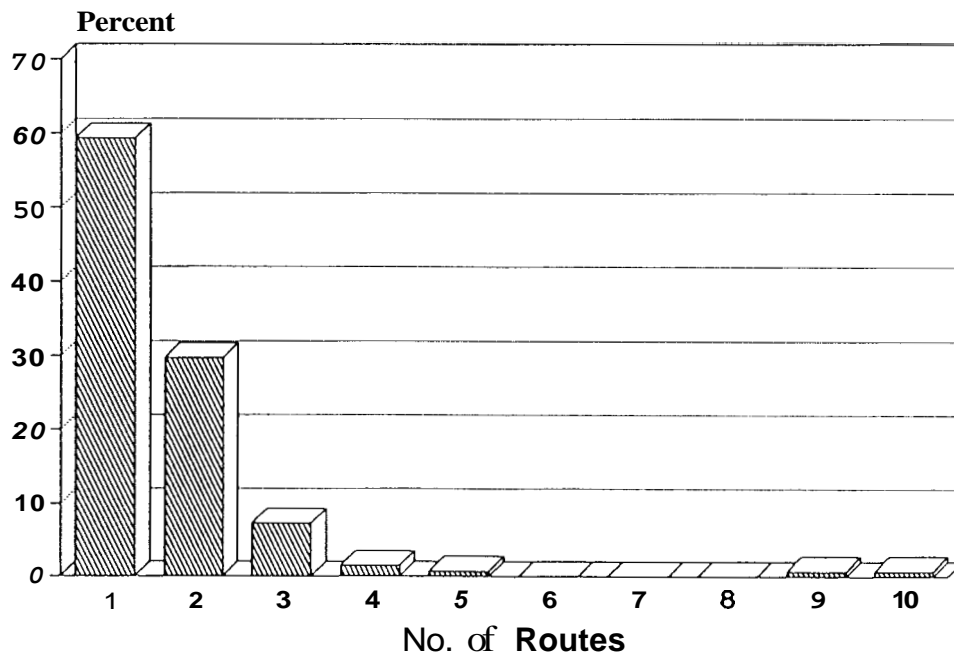


Figure 6: Number of alternative routes for 138 respondents who indicated that they use more than one route

Commute Mode

The commute mode was examined to see if there are particular differences in behavior across users of different modes - particularly if there are differences between commuters driving alone or carpooling. No large differences were realized in connection with the commute mode. However, females tended to carpool more than males; 64.5% of the carpoolers were females, while only 45% of the commuters driving alone to work were females. Testing the hypothesis of independence indicated a dependence between gender and mode choice.

6. ROUTE CHOICE BEHAVIOR

Initial analysis of the survey data using cross-tabulations produced information on general tendencies in the data. About 15.5% of the respondents said they use more than one route to work. **This** may be considered a low percentage, but indicates a very promising potential benefit from an information system that would make more people aware of alternative routes. For those who indicated that they use more than one route to work, the distribution of the number of alternative routes is given in Figure 6. About 50% of the respondents had at least one freeway segment in their primary routes, and 38% had at least one freeway segment in their secondary routes (Figure 7); secondary routes tend to have more surface streets than primary routes, possibly as alternatives for the commuters used to avoid congestion on freeways. The percent of freeway users in the California Statewide Travel Survey data is 46.3% , for trips that start at home and end at work, for head of households who live in the study area, which is very close to the results of the present study (note that even for an area that is generally considered saturated with freeways, 50% of the primary routes involve no freeway at all).

The majority of these respondents use their alternative route(s) between 20 and 40 percent of the days. Figure 8 shows the frequency of driving the secondary route to work in the previous two weeks for respondents who use multiple routes.

The most frequent reason for changing routes, cited by 34% of respondents, is the traffic that the respondents see on the roads. The need to make stops on the way and traffic reports comes

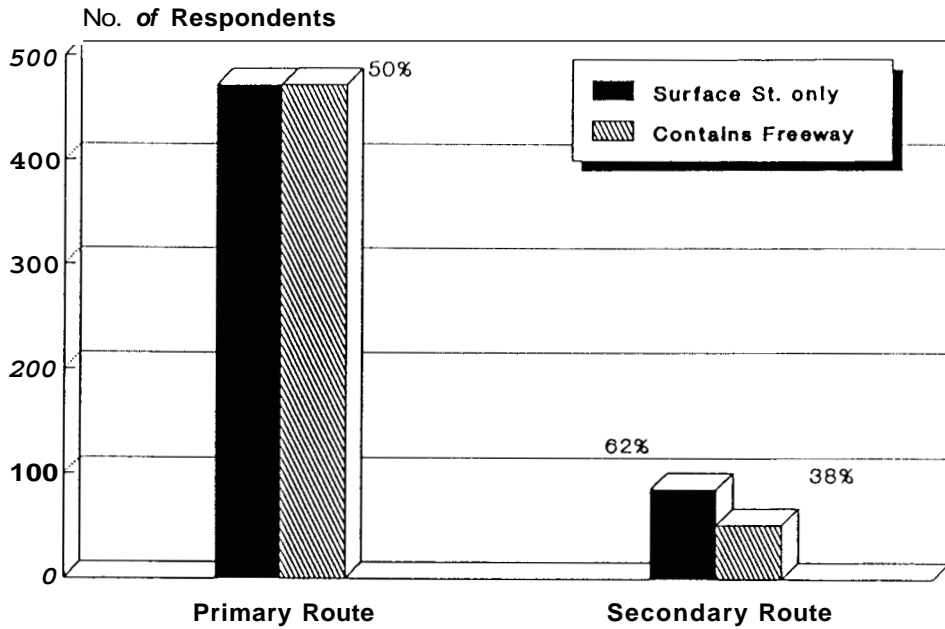


Figure 7: Percent of Freeway and non-Freeway users for both primary and secondary routes

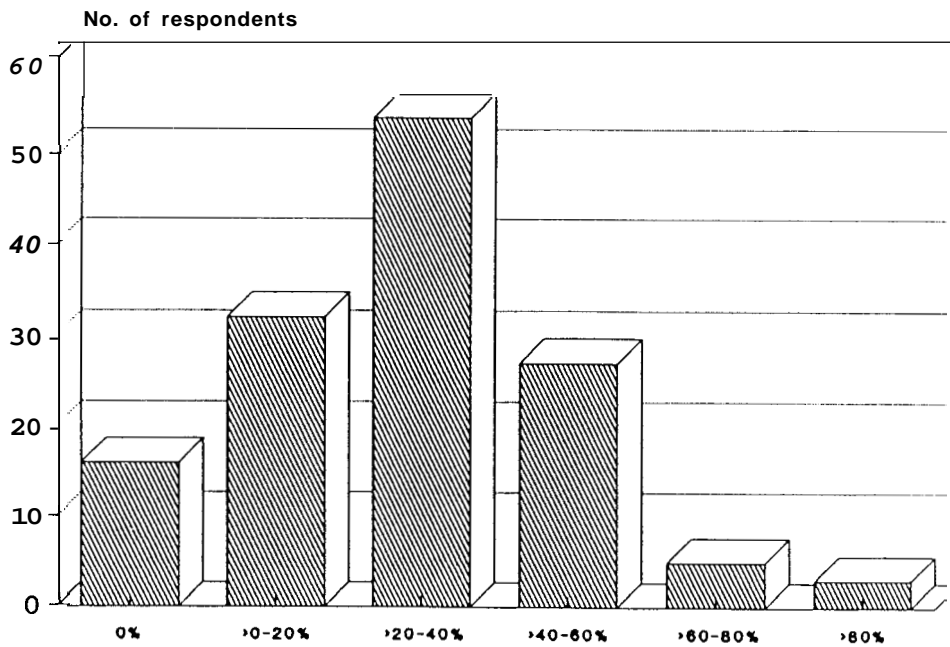


Figure 8: Frequency of driving the secondary route to work in the previous 2 weeks for respondents that use multiple routes

next (15.5% and 14% respectively). Additional reasons include the time of day (8%) and the day of the week (5.5%). Figure 9 illustrates the factors that influence the choice between primary and secondary routes, and the percent of respondents that base their choice on each factor. This indicates that the primary reason for switching routes are the traffic conditions the commuters experience during their trip (they see on the road), an ATIS system could provide them in advance with these conditions so that they can divert before running into the congestion which might cause delays and inconvenience. If the percent of respondents that base their choice on the traffic they see is added to others who base their choice on traffic reports, then about 50% of the commuters depend on information-related sources for choosing their routes.

Individuals with higher incomes tend to report more than one route to work (Figure 10). The fraction of individuals with alternative routes (percent of multiple route users within each income category) increases from 6.7% among those with incomes less than \$25,000 to 28% among those with incomes more than \$100,000. The null hypothesis of independence between income and using alternative routes is rejected. Khattak [7] also found that higher income drivers were more likely to take alternate routes.

Use of secondary routes is directly related to use of traffic reports. Secondary routes are used by 18% (of respondents who listen to traffic reports before leaving home) and 19% (of those who listen to traffic reports while commuting), but only 11% of non-report listeners use secondary routes. The null hypothesis of independence was rejected, indicating that the use of alternative routes and receiving traffic information are statistically associated.

Surface streets are heavily used as secondary routes. About 53% of those who change their routes based on en-route traffic reports take different surface streets, 2% take the same freeway but different on-ramps, 7% take the same freeway with different off-ramps, 18% take different freeways, and 20% take surface streets instead of a freeway. These statistics are based on a question answered by 195 respondents, which is larger than the 138 respondents who indicated that they use more than one route to work, possibly because most respondents didn't perceive minor deviations as a completely alternative route. Also, most of the responses are by freeway users (Figure 11), either changing their surface street or freeway segments. It is important that

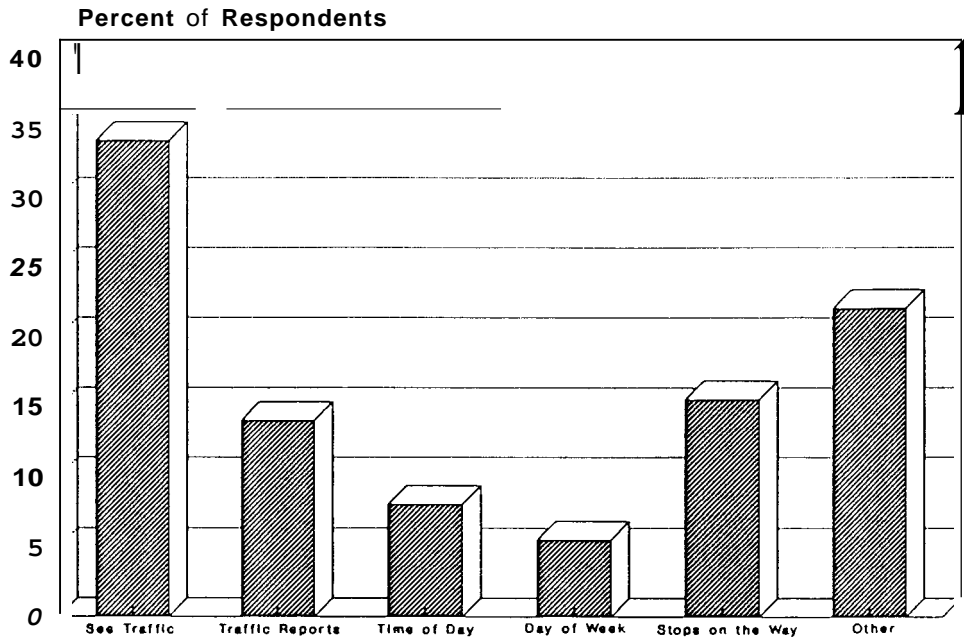


Figure 9: Bases for choice between primary and secondary routes

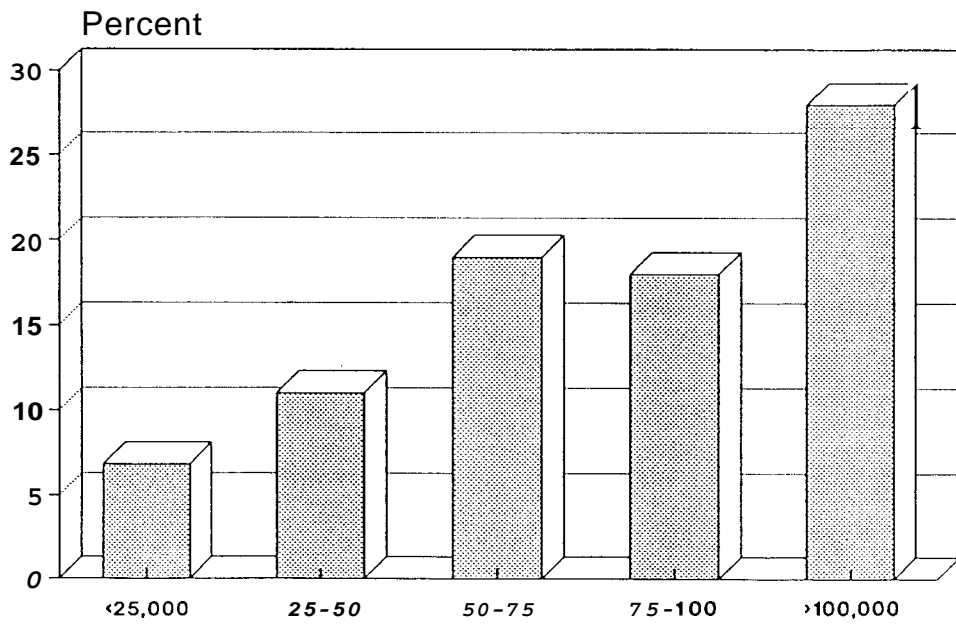


Figure 10: Percent of respondents that use more than one commute route by income

this existing reliance on surface streets be clearly understood when evaluating ATIS development. One of the often cited objections to route guidance is the diversion of traffic to surface arterials. The survey results indicate how frequently this is already occurring. **Real-time** in-vehicle route guidance may not result in dramatic increases in secondary route use, **so** much **as** provide access to more efficient secondary routes. A second phase of the survey will explore this possibility.

Freeway Use

As mentioned before (and depicted in Figure 7), about 50% of the commuters use freeways during their morning commute. Cross-tabulations were used to test whether there are differences in behavior or characteristics between freeway users and non-users. Figure 12 shows the distribution of the commute distance for both freeway users and non-users. Freeways are mostly used for longer distances; the majority of the respondents with long commute distances are freeway users, while most of the **short** trips (below **8** miles) are on surface streets only. Based on Pearson chi-square test of independence, there **is a** significant relationship between freeway use and commute distance.

The majority of the freeway users perceived problems associated with their commute trips **as** either **a** problem or **a** major problem, while the majority of non-freeway users perceived them **as** a minor problem or no problem; 60.6% , 69% and 46% of freeway users versus 23% , 36% and 18% **of** non freeway users, perceived accidents delays, heavy traffic and travel time uncertainty, respectively, **as** either a problem or a major problem. Also, **45%** of freeway users and 27% of non-freeway users reported differences (moderate or substantial) on their usual route. About 25% of freeway users and 7% of non-users said that traffic conditions on their usual routes are either bad or very bad. All the above relationships were tested and were found to be statistically significant; freeway users perceive more problems, uncertainties and traffic variations than do non-freeway users.

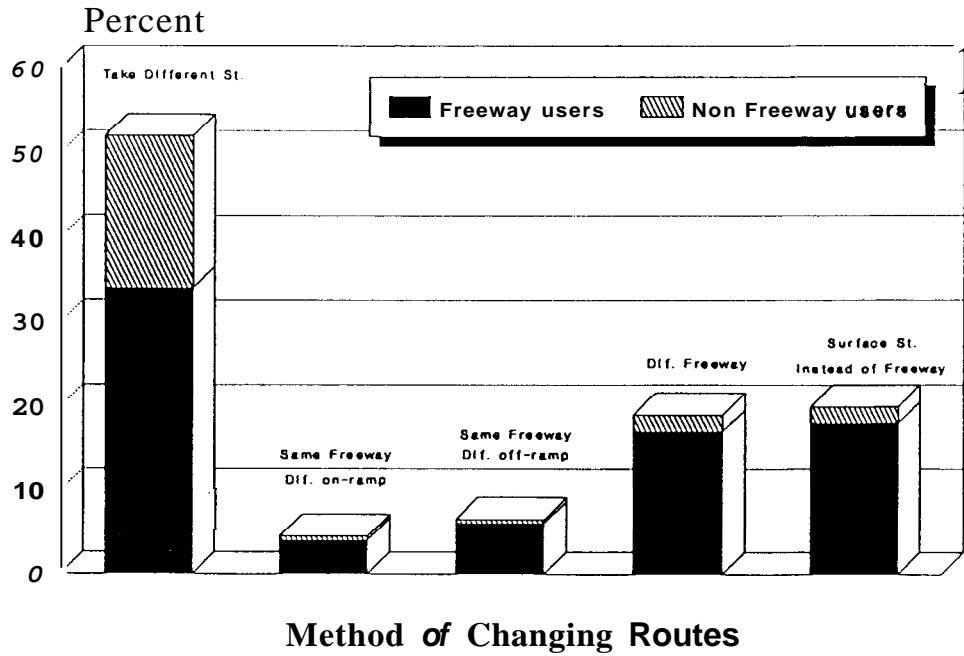


Figure 11: Route changing based on en-route traffic reports
For 195 respondents who reported route changes

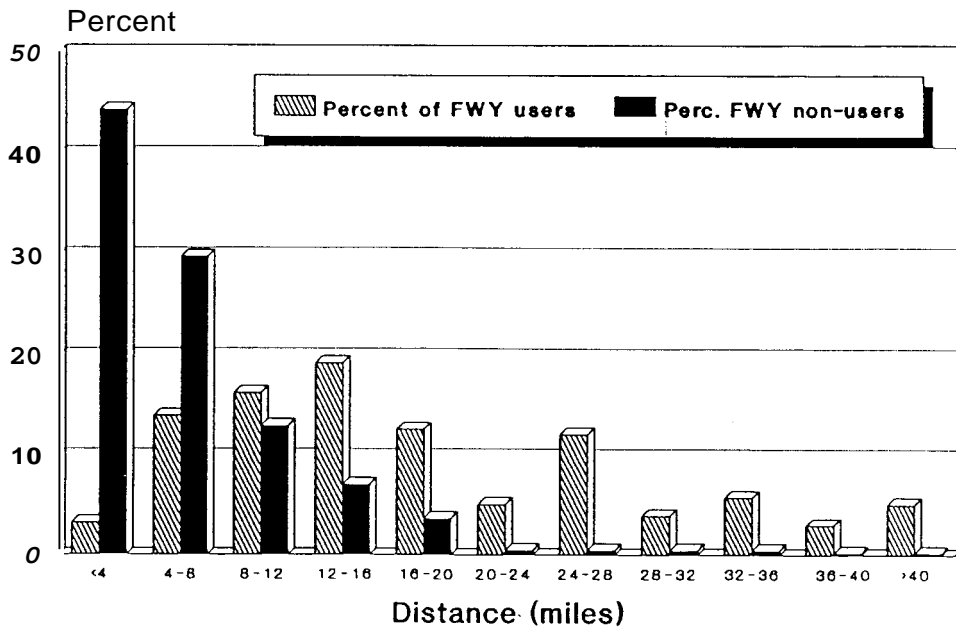


Figure 12: Distribution of commute distance for both freeway and non-freeway users

7. MODELING ROUTE CHOICE

To **assess** commuters' propensity to change routes, we focus on the joint decision on whether or not commuters follow the same route to work every day and whether or not they receive traffic information (pre-trip or en-route). For such a joint decision, the bivariate (two-dimensional) probit formulation is appropriate. Commuters' frequency of route changes based on traffic information is then modeled using negative binomial regression models. Figure 13 summarizes the modeling effort presented in this paper.

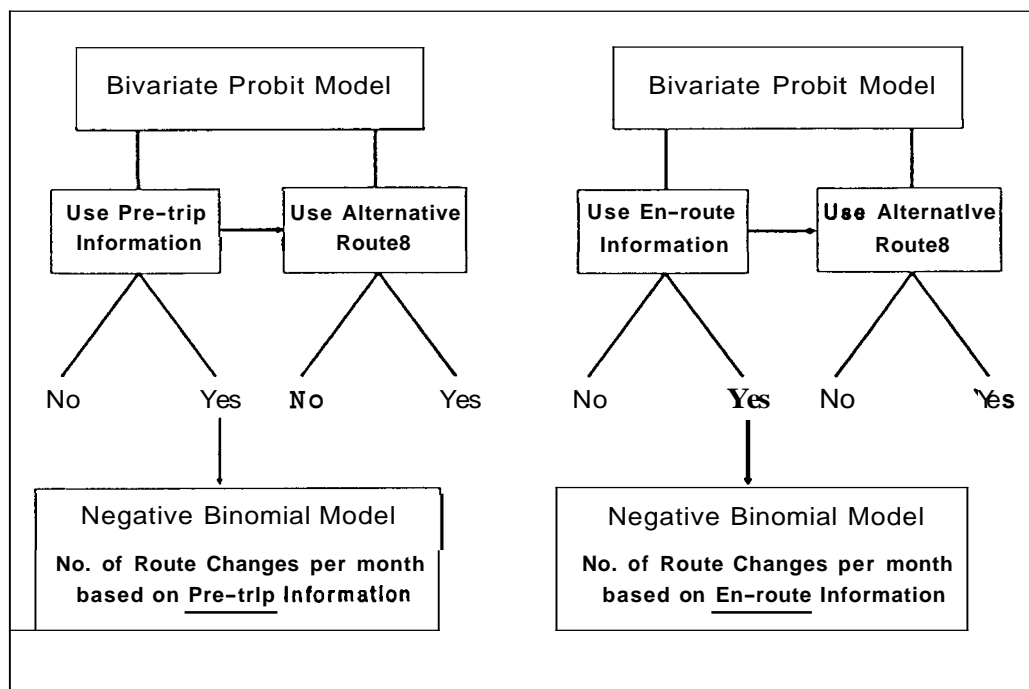


Figure 13: Modeling Structure

7.1. Joint Estimation of Route Switching and Information Choices

There is a need to identify the factors that lead a commuter to **use** single or multiple routes to work, and to receive traffic information. Gaining an understanding on **this** issue will aid in how traffic conditions and other factors affect the use **of** traffic information and route switching. In particular, building a model that predicts route switching behavior **as** a function of information use will aid when evaluating potential effects of **ATIS** on route choice. The modeling effort reported in **this** paper represents an initial effort to probe into the interplay of information use and route choice. The variables considered at this stage of model development include: the attributes of main commute routes, attributes of commuters, and their perception of traffic conditions. It is planned to extend the range of variables in the future to include objectively measured traffic characteristics for the respective commuters' main and alternative routes.

Methodological Approach

The simultaneous bivariate probit model structure is used in order to identify the contributing factors that influence route switching behavior, **and** affect the likelihood of receiving traffic information.

Considering in **this** case two binary choices; whether a respondent receives traffic information ($Y_1 = \{0,1\}$), and whether he uses more than one route to work ($Y_2 = \{0,1\}$). Then the two choices may be represented by a simultaneous equation system **as** follows:

$$Y_1 = \beta X_1 + \varepsilon \quad (1)$$

$$Z_1 = \begin{cases} 1 & \text{if } Y_1^* \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$Y_2^* = \alpha X_2 + \theta Z_1 + \xi \quad (2)$$

$$Z_2 = \begin{cases} 1 & \text{if } Y_2^* \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

where;

Y_1^* = latent variable indicating whether the respondent listens to traffic information

Z_1 = observed choice (1 if the respondent listens to information, and 0 otherwise)

Y_2^* = latent variable indicating if the respondent is a multiple routes user

Z_2 = observed choice (1 if the respondent is a multiple route user, and 0 if he uses exactly one route every day to work)

B, a = coefficient vectors

θ = scalar coefficient

X_1, X_2 = explanatory variables influencing choice behavior

ε, ξ = random error terms.

Assuming ε and ξ are correlated ($E(\varepsilon\xi) \neq 0$), then the two equations should be estimated simultaneously using the full-information maximum likelihood (FIML) or sequentially equation by equation using the limited-information maximum likelihood (LIML) [17,18]. The FIML is desirable because it offers consistent and efficient estimates, while allowing to test the error correlation across equations. Thus FIML is adopted in this study.

Distributional assumptions need to be made on the random error terms ε and ξ in order to express response probabilities. The probit formulation, in a situation involving two binary choice endogenous variables, would imply that the joint distribution of ε and ξ is given by the bivariate standard normal distribution.

For the system of equations represented in equations 1 and 2, the **FIML** function for the bivariate probit is now developed. Define Sample strata as:

S_1 : $Z_1=1$ and $Z_2=1$

S_2 : $Z_1=1$ and $Z_2=0$

S_3 : $Z_1=0$ and $Z_2=1$

S_4 : $Z_1=0$ and $Z_2=0$

The likelihood function for the first set of observations, S_1 , is derived by considering the joint probability of the events, $Z_1=1$ and $Z_2=1$:

$$\begin{aligned} \Pr[Z_1=1, Z_2=1] &= \Pr[Y_1^* \geq 0, Y_2^* \geq 0] \\ &= \Pr[\varepsilon \geq -\beta X_1, \xi \geq -\alpha X_2 - \theta Z_1] \\ &= \int_{-\beta X_1}^{\infty} \int_{-\alpha X_2 - \theta Z_1}^{\infty} f(\varepsilon, \xi) \, d\varepsilon \, d\xi \end{aligned}$$

where f is the standard bivariate normal density function:

$$f = \frac{2n}{\sqrt{(1 - \rho^2)}} \exp \left[-\frac{(\varepsilon^2 - 2\rho\varepsilon\xi + \xi^2)}{2(1 - \rho^2)} \right] \quad (3)$$

and ρ is the correlation coefficient between ε and ξ .

The likelihood function for this set of observations is:

$$L_1 = \prod_{S_1} \int_{-\beta X_1}^{\infty} \int_{-\alpha X_2 - \theta Z_1}^{\infty} f(\varepsilon, \xi) \, d\varepsilon \, d\xi \quad (4)$$

Similarly, L_2 , L_3 and L_4 could be derived. Therefore, the likelihood function for the entire sample will be:

$$\begin{aligned} L &= \prod_{S_1} \int_{-\beta X_1}^{\infty} \int_{-\alpha X_2 - \theta Z_1}^{\infty} f(\varepsilon, \xi) \, d\varepsilon \, d\xi \quad \prod_{S_2} \int_{-\beta X_1}^{\infty} \int_{-\infty}^{-\alpha X_2 - \theta Z_1} f(\varepsilon, \xi) \, d\varepsilon \, d\xi \\ &\quad \prod_{S_3} \int_{-\beta X_1}^{\infty} \int_{-\infty}^{-\alpha X_2 - \theta Z_1} f(\varepsilon, \xi) \, d\varepsilon \, d\xi \quad \prod_{S_4} \int_{-\infty}^{-\beta X_1} \int_{-\infty}^{-\alpha X_2 - \theta Z_1} f(\varepsilon, \xi) \, d\varepsilon \, d\xi \end{aligned} \quad (5)$$

Parameter vectors β , α , θ and ρ are estimated so as to maximize L. The statistical significance of the coefficient θ will indicate whether state dependence is present. Also, significant error correlation between ϵ and ξ (ρ) will indicate the presence of unobserved individual factors (heterogeneity) that affect both choices of route and receiving information.

Estimation Results for the Bivariate Probit Models

Two bivariate probit models were developed after investigating several alternative model formulations. The first estimates whether the respondent often receives traffic reports before leaving home to work (pre-trip), and whether he is a multiple route user. The second estimates whether the respondent often receives traffic reports while driving to work (en-route), and whether he is a multiple route user.

Estimation results for the pre-trip information / multiple route user model are given in Table 6. All variables included are self-explanatory and their coefficients are readily interpretable. Turning first to the pre-trip information model, we find that people who perceive no variation in traffic conditions on their usual commute route are less likely to listen to pre-trip traffic reports. Females, long distance commuters and/or respondents who reported uncertainty in travel time as a major problem, are more likely to listen to these reports.

For multiple route choice, high income ($\geq \$75,000$), high level of education (college graduate or completed some college), and the number of days driving to work in two weeks increases the likelihood of using multiple routes. The positive coefficient of receiving pre-trip information indicates that commuters that receive pre-trip information are more likely to use more than one route to work, while the significance of the variable indicates the presence of state dependence of Y_2^* on Y_1^* . The significance of the correlation between the two error terms indicates the presence of heterogeneity. The unexpected negative sign indicates the presence of unobserved factors that reversely affect the two behavioral aspects.

Table 6: Bivariate probit model estimating whether the respondent often receives traffic reports before leaving home to work, and whether he is a multiple route user

	Coefficient	t-statistic
PRE-TRIP INFORMATION MODEL		
Constant	-0.4164	-3.790
X , No variation in traffic conditions dummy (1 if no variation is perceived, 0 otherwise)	-0.3615	-3.685
X , Female dummy (1 if female, 0 otherwise)	0.1106	1.154
X , Uncertainty of travel time dummy (1 if reported that trip time uncertainty is a major problem, 0 otherwise)	0.4369	3.237
X , Distance from home to work	0.0133	3.405
MULTIPLE ROUTE MODEL		
constant	-2.0331	-6.953
X , Income dummy (1 if income \geq \$75,000, 0 otherwise)	0.3029	2.438
X , Receiving pre-trip information dummy (1 if receive pre-trip information, 0 otherwise)	1.0027	2.740
X , No. of driving days in the last 2 weeks	0.0324	1.269
X , Level of education dummy (1 if respondent is a college <i>grad.</i> or completed some college, 0 otherwise)	0.4091	2.551
Correlation	-0.5180	-2.386
<u>Summary Statistics</u>		
Log Likelihood at zero = -1061.761		
Log Likelihood at market share = -790.804		
Log Likelihood at convergence = -758.191		
Likelihood ratio index = 0.286		
Number of observations = 733		
Percent correct predicted = 72%		

Note: Variables' coefficients are defined for receiving reports and multiple route use

Table 7: Bivariate probit model estimating whether the respondent often receives traffic reports while driving to work, and whether he is a multiple route user.

	Coefficient	t-statistic
EN-ROUTE INFORMATION MODEL		
Constant	-0.3035	-2.823
X , No variation in traffic conditions dummy (1 if no variation is perceived, 0 otherwise)	-0.2449	-2.426
X , College graduate dummy (1 if respondent is a college <i>grad</i> , 0 otherwise)	0.1950	2.002
X , Uncertainty of travel time dummy (1 if reported that trip time uncertainty is a major problem, 0 otherwise)	0.7086	4.513
X , Distance from home to work	0.0269	6.572
MULTIPLE ROUTES MODEL		
Constant	-2.0614	-5.923
X , Income dummy (1 if income \geq \$75,000, 0 otherwise)	0.3064	2.333
X , Receiving en-route information (1 if receive pre-trip information, 0 otherwise)	0.5317	1.665
X , No. of driving days in the last 2 weeks	0.0358	1.282
X , Level of education dummy (1 if respondent is a college <i>grad.</i> or completed some college, 0 otherwise)	0.4154	2.442
Correlation	-0.1742	-0.825
Summary Statistics		
Log Likelihood at zero = -1061.761		
Log Likelihood at market share = -815.902		
Log Likelihood at convergence = -762.335		
Likelihood ratio index = 0.282		
Number of observations = 733		
Percent correct predicted = 84.9%		

Note: Variables' coefficients are defined for receiving reports and multiple route use

Estimation results for the en-route information / multiple route user model are given in Table 7. The model is similar to the previous model, except that gender is substituted by college graduate dummy, which significantly increases the likelihood that the respondent receives en-route traffic reports. The positive coefficient of receiving en-route information indicates that commuters that receives en-route information are more likely to use more than one route to work, while the significance of the variable (only at 90% level of significance) indicates the presence of state dependence of Y_2^* on Y_1^* . The insignificance of the correlation between the two error terms indicates that heterogeneity is not present.

7.2. Frequency of Changing Routes Based on Information

To assess commuter frequency in changing routes, an appropriate statistical modeling technique is needed. The Poisson distribution was disregarded because the mean and variance of the dependent variables are different, indicating substantial over dispersion in the data. Such over dispersion suggests a negative binomial model. The negative binomial model is an extension of the Poisson regression model and allows the variance of the process to differ from the mean.

Methodological Approach

This section is drawn on Greene [19]. The negative binomial model arises from the Poisson model by specifying:

$$\ln \lambda_i = \beta X_i + \epsilon \quad (6)$$

where;

β = vector of estimable parameters

X_i = vector of commuting and socioeconomic characteristics for individual i

ϵ = error term, where $\exp(\epsilon)$ has a gamma distribution with mean one and variance α^2 . The resulting probability distribution is

$$\Pr[Y=y_i \mid \epsilon] = \exp[-\lambda_i \exp(\epsilon)] \lambda_i^{y_i} / y_i! \quad (7)$$

Integrating ϵ out of this expression produces the unconditional distribution of Y_i . The formulation of this distribution which is used for optimization is:

$$\Pr[Y=y_i] = \Gamma(\theta + y_i) / [\Gamma(\theta)\Gamma(y_i!)] u_i^\theta (1-u_i)^{y_i} \quad (8)$$

where;

$P[Y=y_i]$ = probability of commuter i making y changes in a specified period of time.

$$u_i = \theta / (\theta + \lambda_i)$$

$$\theta = 1/\alpha$$

λ_i = Poisson parameter for commuter i .

This model has an additional parameter α , such that

$$\text{Var}[y_i] = E[y_i]\{1 + \alpha E[y_i]\} \quad (9)$$

This is a natural form of overdispersion in that the overdispersion rate is:

$$\text{Var}[y_i]/E[y_i] = 1 + \alpha E[y_i] \quad (10)$$

Such an approach is well suited to the route application since it accounts for the no-change option ($y_i = 0$) as well as all other possible non-negative integer outcomes [20]. The negative binomial model can be estimated by standard maximum likelihood methods.

Testing the Existence of Selectivity Bias

Before proceeding with the estimation of the negative binomial models, it is important to test for possible selectivity bias. Selectivity bias could be present if the commuters observed to be changing routes were a self-selected group with behavior that systematically differed from those commuters not observed to be changing routes. Such selectivity creates a problem because we have frequency data only on those individuals observed changing routes. If their behavior systematically differs from those not observed changing routes, our estimates of β will be biased.

Bias in standard regression equations have been derived by numerous researchers (Heckman [21], Dubin and McFadden [22]). However, developing correction techniques for count data (i.e. based on a negative binomial regression) has not been done and is likely to be a difficult task because a closed form expression for the expected value of the gamma error term (see equation 6) conditioned on the bivariate probit error terms must be developed (i.e. $E(\epsilon \mid \epsilon\xi)$). Such a formulation is beyond the scope of this paper. However, we conducted a suggestive test of this matter using standard discrete/continuous correction procedure (Manning [23]). In doing so, we approximate the bivariate probit model with a simple independent binary logit

model, and approximate the negative binomial regression model with a standard regression model.

The correction terms in both models (number of times per month changing routes based on pre-trip information, and number of times per month changing routes based on en-route information) were statistically insignificant, suggesting selectivity bias is not present. Therefore, estimating the negative binomial models without possible error correlation between the bivariate probit and the negative binomial is not likely to be a significant source of error.

Estimation Results for the Negative Binomial Models

Two models were developed, the first modeling the number of route changes per month based on listening to pre-trip traffic reports, and the second modeling the number of route changes per month based on listening to en-route traffic reports.

The first model is illustrated in Table 8. The model showed that commuter's perceptions have an important effect on the number of route changes, that is, if the respondent perceives substantial variation in traffic conditions from day to day on his primary route, then he is likely to make more route changes per month. If information is perceived to be accurate, then it will have a positive effect on the number of changes per month - dummy variables representing report accuracy were attempted but the variable appeared to be linear, therefore, the ordered response **was** used. Commuters' perception of the accuracy of traffic reports are gained through experience. Information accuracy and experience influence the commuters' decision to change routes. A positive association between report accuracy and willingness to divert has also been observed in separate experiment studies of information advice accuracy [2,3,4]. These survey results validate the experiments' findings.

From the socioeconomic factors, high level of education (college graduates) has a positive impact on the number of route changes per month. **Also** from the commute characteristics, the log of travel time on the most frequently used route has a positive impact on the number of route changes per month indicating that longer commutes make travelers more likely to change routes. A possible explanation can be that time-consuming commutes lead to a greater awareness and use of alternate routes, based on pre-trip information. However, the log transformation indicates that **this** effect diminishes with increasing travel time. The significance of the over dispersion parameter (**α**) indicates that the negative binomial formulation is preferred to the more restrictive Poisson formulation.

Table 8: Negative Binomial Model of the number of times per month changing route to work based on pre-trip reports.

	0	t-statistic
0, constant	-2.7351	-2.432
X, Perceived Variation in traffic conditions dummy (1 if traffic conditions are substantially different from day to day on the usual commute route, 0 otherwise)	0.7520	1.509
X ₂ , Perceived accuracy of traffic reports (1 not at all accurate, 2 not very accurate, 3 somewhat accurate, 4 very accurate, 5 extremely accurate)	0.3624	2.420
X, College graduate dummy (1 if college graduate, 0 otherwise)	0.3548	1.484
X, Log driving time on last trip using the usual route	0.5079	2.193
α overdispersion parameter	2.0657	5.903
Summary Statistics		
Log Likelihood at zero = -833.809		
Log Likelihood at convergence = -415.779		
$\sigma^2 = 0.501$		
Number of observations = 238		

The second model (the frequency of route changes per month based on en-route information) is presented in Table 9. The results show that carpool dummy has a positive effect on the number of route changes per month based on en-route traffic reports, once carpoolers are together on the road, en-route information influence their decision to change routes.

Perceiving substantial traffic variation and bad traffic conditions on the usual route increase the frequency of route changes. **Also** perceiving information to be accurate has a positive effect (dummy variables representing report accuracy and traffic conditions were attempted but the variables appeared to be **linear**; therefore, the ordered responses were used). Individual's perception of reality **is** important because it ultimately drives their behavior, which indicates that accurate traffic information is vital for commuters that perceive variations or bad traffic conditions on changing routes.

The **model** also shows that freeway users tend to change routes more frequently based on en-route information, possibly **as** a means to avoid congestion. The positive coefficient of the log

of commute distance indicates that longer distances cause route changes based on en-route information, using the log indicates that **this** effect is non-linear, i.e. stronger in the shorter distances. Again, the significance of the overdispersion parameter (α) shows that the negative binomial formulation is a preferred specification.

Table 9: Negative Binomial Model of the number of times per month changing route to work based on en-route reports.

	β	t-statistic
β_0 constant	-2.3856	-4.594
X, Carpool dummy (1 if mode is carpool, 0 otherwise)	0.4732	1.684
X, Perceived Variation in traffic conditions dummy (1 if traffic conditions are substantially different from day to day on the usual commute route, 0 otherwise)	0.6171	1.615
X, Rating of traffic conditions (1 very good, 2 good, 3 OK, 4 bad, 5 very bad)	0.2507	2.666
X, Perceived accuracy of traffic reports (1 not at all accurate, 2 not very accurate, 3 somewhat accurate, 4 very accurate, 5 extremely accurate)	0.2976	2.911
X, Freeway user dummy (1 if uses fwy, 0 otherwise)	0.4205	1.566
X, Log commute distance	0.1903	1.409
α overdispersion parameter	2.1492	7.971
Summary Statistics		
Log Likelihood at zero = -1426.647		
Log Likelihood at convergence = -675.750		
$\sigma^2 = 0.526$		
Number of observations = 443		

8. SUMMARY AND CONCLUSIONS

This paper is based on a computer-aided telephone interview (CATI) survey carried out as part of a research project at the University of California at Davis, designed to gain a basic understanding of drivers' route choice behavior, to collect detailed information about their commute routes, and to explore how commuters use traffic information in deciding about routes to travel to work. There is **still** little understanding of commuters' route choice, which is essential for the development of ATIS systems. As previous research has shown a basic understanding of how drivers choose or change routes in the absence of information is still needed in order to gain an understanding of route choice behavior in the presence of information [11].

Initial analysis using general descriptive statistics showed several tendencies in the commuters' route choice decisions. Only 15.5% of the respondents reported that they don't always follow the same exact route to work, which indicates the potential benefit from an information system that would make more commuters aware of alternative routes. Surface **streets** are heavily used as secondary routes, the survey results indicate how frequently diversion of traffic to surface arterials is already occurring, perhaps in an inefficient way. Real-time, in-vehicle route guidance may provide access to more efficient secondary routes.

The desire to decrease the trip time, receiving traffic reports, and time the commuters leave their homes, were among the reasons reported for changing the primary route. High income and high level of education were among the socio-demographic factors for using more than one route. Other factors, such **as** the commute distance, didn't seem to have any significant effect on using alternative routes.

About 36.5% of the respondents listen to traffic reports before leaving their homes, and 51.2% listen while driving. In general 60.1% listen to reports at home and/or en-route. Most respondents who receive traffic information perceived traffic reports to be either accurate or somewhat accurate.

Respondents that perceive traffic conditions on their usual route **as** bad or substantially different from day to day, were more likely to listen to traffic reports either before their departure, during driving, or both. The data **also** suggests that respondents that reported heavy traffic conditions

on the freeway segment they use were more likely to receive traffic reports before leaving their homes, which indicates that commuters **try** to find in advance about the conditions on the freeways they use.

The results also show that gender attributes influence the commute behavior. Females tend to listen to pre-trip traffic reports and carpool more than males, while they tend to use freeways less than males.

Bivariate probit models were developed to determine the factors that influence information use and the propensity to use alternative routes. The models showed significant effect of income, education, frequency of driving to work, and listening to traffic reports on the commuters' route choice. **Also** perceived variation in traffic conditions, gender, commute distance, and travel time uncertainty affect the likelihood of listening to traffic information. Using the effect of traffic flows **as** the specific attributes of the route segments, might be **a** possible extension of **this** modeling effort.

Negative binomial models were developed to **assess** commuters frequency of changing routes. Two models were developed, the first modeling the number of route changes per month based on pre-trip traffic reports, and the second modeling the number of route changes per month based on en-route traffic reports. The models showed significant effect of commuters' perceptions of the accuracy of traffic reports and variation in traffic conditions, travel time, and the level of education on the frequency of changing routes based on pre-trip information. Also, traffic conditions, perceptions of information accuracy and traffic variation, freeway use, commute distance and carpool, were among the variables influencing the frequency of route changes based on en-route traffic information.

The strength of **this** survey is the detailed information collected on the respondents' commute routes. Future research is ongoing to extend the analysis and modeling effort to the level of each segment on the commute route, and using objectively measured route attributes.

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