Improving Motorist Information Systems

Towards a User-Based Motorist Information System for the Puget Sound Area

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16. ABSTRACT

This report documents new knowledge of Puget Sound freeway commuter behavior and information needs, relevant to the design and development of a motorist information system for the Seattle area. Methodological innovations resulted in a larger, more relevant sample; more complex and varied data; and a finer grain of analysis than previous efforts to survey motorist behavior. Findings are relevant not only to driver information systems in particular, but also to transportation management in general. Commuters were found not to be a single, homogeneous audience for motorist information, but rather to consist of four subgroups, which we labeled: (1) **route changers,** (2) **non-changers,** (3) **route and time changers**, and (4) **pre-trip changers**. Commuters were more receptive to motorist information delivered at home than to information delivered on the freeway. Most commuters were inflexible about changing transportation mode, but *pre-trip changers* were somewhat flexible and more likely to change mode than to change route while on the freeway. The most flexible driving decision was the departure time of *route and time changers* and *pre-trip changers*, yet the least flexible driving decision was the departure time of *route changers* and *non-changers*. Commuters were fairly flexible to on-road route changes, but less flexible than to changing pre-trip routes based on traffic information received prior to departure. Commercial radio was the preferred medium for on-road traffic information, while HAR and VMS were either not used or not generally perceived as helpful. Whatever the delivery medium, commuters questioned the credibility of motorist information.

The report describes how the identification, analysis, and targeting of susceptible driver groups can improve the design of motorist information systems. Recommendatios are also presented to improve commuter response to and use of HAR and VMS.

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IMPROVING MOTORIST INFORMATION SYSTEMS:

TOWARDS A USER-BASED MOTORIST INFORMATION SYSTEM FOR THE PUGET SOUND AREA

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DISCLAIMER

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SUMMARY

Advanced Driver Information Systems (ADIS) are a promising approach to relieving problems related to urban traffic congestion. However, the output of an ADIS must not only be thought of as a message or display, but also as the ability of that message or display to impact drivers. The design of a motorist information system should therefore be based not only on the capabilities of communication technology, but even more importantly on an awareness of driver behavior and information needs.

This project surveyed Puget Sound freeway commuters in order to determine their driving behavior and information needs relevant to the design and development of a motorist information system for the greater Seattle area. Building on previous efforts in driver analysis by transportation researchers, our methodology proved extremely successful, resulting in a larger sample, more complex and varied data, and a finer grain of analysis than previous efforts to survey motorist behavior. Analysis of our extensive data set has lead to important findings and conclusions not only for the design of motorist information systems in particular, but also for transportation management in general.

Particularly significant was our use of *cluster analysis* and other inferential techniques to discover, confirm, and explore commuter sub-groups. Commuters are not a single, homogeneous audience for motorist information. We found four commuter groups, and labeled them: (1) **route changers** (RC), willing to change routes before or during their commute but unwilling to change departure time or transportation mode (20.6%); (2) **non-changers** (NC), unwilling to change departure time, route, or transportation mode (23.4%); (3) **route and time changers** (RTC), willing to change route and departure time, but not transportation mode (40.1%); and (4) **pre-trip changers** (PC), those unwilling to change route while driving, but willing to change time, route, or even mode prior to leaving their residence (15.9%). Not only are certain commuters more flexible about a given driving behavior than others, but those commuters who are less flexible are also less likely to be aware of available information that could impact that decision.

The identification of driver groups and driver decisions is central to the design of motorist information systems. The goal of these systems is to improve traffic flow, not to be equally useful to all drivers at all times. This improvement in traffic flow can be achieved by affecting the behavior of relatively small percentages of commuters. An ADIS should deliver motorist information targeted to impact particular driving decisions and tailored to those groups most likely to be impacted.

Pre-trip delivery of motorist information is a complex but particularly promising area. Commuters were far more receptive to motorist information delivered at home than they were to information delivered on the freeway, and (except for the NC) were flexible about changing routes based on traffic information received prior to departure. Most commuters were inflexible about

changing transportation mode, though one commuter type (PC) was somewhat flexible and should be targeted for information relating to mode choice (in fact, pre-trip changers were more likely to change mode than they were to change route while on the freeway).

Perhaps most promising of the pre-trip decisions is departure time. Commuters were dramatically split in their departure time flexibility. The single most flexible driving decision was the departure time of the RTC and PC groups, yet the single least flexible driving decision was the departure time of the RC and NC groups. By tailoring pre-trip information to those commuters identified as susceptible to altering departure time, we should be able to spread out the commute and reduce peak congestion.

While commuters were not generally receptive to traffic information delivered on the freeway, they were fairly flexible to on-road route changes (though less so than pre-trip route changes). Commercial radio was far and away the preferred medium for delivery of on-road traffic information, while Highway Advisory Radio (HAR) and Variable Message Signs (VMS) were either not used or not generally perceived as helpful. However, the follow-up survey showed that exposure to positive examples leads to a marked improvement in commuter response to new mediums. HAR and VMS can be improved by (1) targeting those commuters who tend to change route while driving, (2) integrating and coordinating HAR and VMS with home delivery systems to provide feedback as well as updated information, (3) improving message content, (4) keeping messages relevant to particular driver decisions, or to feedback and reinforcement of those decisions, (5) incorporating an indication of timeliness into messages, and (6) integrating HAR and VMS more closely with real-time gathering of traffic data.

Whatever the delivery medium, commuters questioned the credibility of motorist information. In addition, when they did modify their behavior, commuters did not know whether or not they had made the correct decision. Having decided to use an alternate route, commuter stress increased, rather than decreased. If we are to reinforce commuter modification of driving behavior, it is necessary to include a feedback mechanism in any motorist information system.

For future implementation, we propose (1) extending our survey to include east/west and southern Seattle commuters; (2) sharing our expanded analysis of commuter behavior with state agencies, lawmakers, and public groups to help shape state transportation policy; (3) developing a front end/interface to the current system for gathering and displaying real-time traffic data, capable of converting traffic data into information tailored to impact susceptible commuter groups as to their choice of route, mode, and time of commute; (4) selecting and developing home delivery mechanisms for the information produced by this front end, (5) integrating on-road and home delivery of motorist information to provide feedback and confirmation of system reliability; (6) developing and implementing state-wide guidelines for HAR and VMS; and (7) performing additional research on motorist response to traffic message content.

INTRODUCTION AND RESEARCH APPROACH

BACKGROUND

The rapid growth in the number of cars on U.S. highways has generated numerous economic and public policy problems. Some of the most pressing problems can be traced directly to the significant increase in urban commuting traffic, both on freeways and arterials. For example, in a recent survey of more than 4,000 businesses in the greater Seattle area, nearly one in five indicated that traffic is forcing them to consider relocation. And this, of course, is only one of the numerous economic and social problems that increased traffic has brought to U.S. cities. Other traffic related problems include: increasing noise and air pollution; loss of productivity due to decreased worker performance; and multi-billion dollar costs for construction and road maintenance, as well as for potential high cost alternative forms of transportation.

A number of major new efforts to alleviate urban traffic congestion center around motorist information. Foreign development efforts in the areas of motorist information and navigation systems are already well underway in West Germany, Great Britain, France, and Japan; in Germany these efforts are already to the point of public testing. In the U.S., recent initiatives in this area have been spurred by the Federal Highway Administration's announcement of a High Priority National Program Area in "Advanced Motorist Information Systems for Improved Traffic Operations." The single largest U.S. effort at this time is a cooperative project between FHWA, California Department of Transportation, and General Motors known as "Pathfinder." Pathfinder, as its name implies, focuses on the assessment of communications technology for route guidance and in-car navigation in response to incidents and traffic congestion.

The Advanced Motorist Information System (ADIS) approach assumes that by providing motorists with timely and appropriately designed traffic information, coupled with route guidance to encourage alternatives, driver decision-making and behavior can be modified to both improve short-term motorist response to incidents and peak hour congestion, and to modify long-term behavior of commuters. This would result in more efficient use of existing transportation resources, which in turn would lessen the need for costly new roadway construction or alternative transportation facilities like light rail.

Of course providing motorists with timely, accurate, and effective information is only one of many possible approaches to reducing urban congestion, and it is highly unlikely that any single solution will produce a quick fix. There are, however, a number of important benefits which may result from information-based solutions. These include:

Economic: Motorist information systems are relatively inexpensive. Even considering the full range of ADIS development issues (e.g. understanding commuter behavior and decision-making, gathering real-time traffic data, converting that data into effective driver information, and delivering that information at appropriate decision points), the cost of an effective motorist information system is still a fraction of construction and maintenance costs for either additional roadways or alternative transportation systems.

Social: Motorist information systems have less potential negative impact on major social areas such as land use, environmental impact, and population dispersion, than do either alternative transportation systems or new roadway construction.

Political: Motorist information systems fit well into the American political philosophy since they represent a consumer-based, free choice approach to traffic congestion. ADIS provide drivers with the best possible information available and leave them to make their own decisions based on that information. This is in contrast to the development of controlled guidance systems or the many possible "enforced" solutions such as requiring a minimum number of drivers in cars during peak hours.

While motorist information systems are theoretically attractive, their practical design raises a number of considerations and problems.

PROBLEM STATEMENT

Generally, past efforts to address traffic problems have focused on additional resources to meet high cost, high technology solutions. While additional resources are needed, the application of technological solutions to human-based problems first requires a thorough understanding of the intended users of that technology. Thus, engineering solutions to transportation problems should be developed within the context of a thorough understanding of motorist behavior. Otherwise, we cannot be confident that these "solutions" will produce the desired effects.

This is particularly true in the case of solutions based on motorist information. No matter how rapidly and accurately it reflects the current state of the transportation system, information alone is not enough to improve the situation. People must respond to that information, and it is this response which actually improves the environment in which the information system operates. The output of a motorist information system, therefore, must not only be thought of as a message or display, but also as the ability of that message or display to impact drivers.

There are many factors that determine the impact of motorist information. Some are characteristics of the communication itself, such as timeliness, content, delivery point, medium, and clarity. Others are characteristics of the receiver of the communication, such as driving routines, willingness to change, decision procedures, awareness of alternatives, and flexibility. The design of a motorist information system must be based not only on the capabilities of communication technology, but even more importantly on an awareness of driver behavior and information needs.

Further complicating matters is the fact that motorists are not a homogeneous audience for traffic information. Rather, they are a complex mixture of driver types, differing in personality, geography, travel demands, social situations, economic status, etc. A single message cannot identically impact all motorists, nor would we generally want it to. The designer of motorist information needs to understand the complex driver audience, particularly if he or she wishes to target specific sub-groups to increase the effectiveness of particular messages.

Much information about commuters, particularly demographic data, already exists; this report cites numerous relevant studies. No existing studies, however, describe motorist behavior patterns and decision-making processes with sufficient detail or focus to be useful for information system design. In particular, extremely little is known about Puget Sound commuters, and obtaining this information was the first step towards developing an effective, user-based motorist information system for the Puget Sound area.

RESEARCH APPROACH AND METHODOLOGY

The first step towards designing a motorist information system is to understand who are the drivers you are trying to impact, what driving decisions they make, where they make them, and on what basis they are made. The second step is the application of that understanding to the design, development, and testing of the system. Therefore, we first needed to conduct a "Motorist Information Survey" designed to gather data about motorist activities and behaviors, as well as to help us analyze the potential for changing these behaviors through the design and delivery of motorist information. Numerous complex decisions relating to this research approach were made during the survey design phase of the project, with many of these decisions relying on information gathered during the state-of-the-art review conducted during the initial phases of the overall project.

(See Appendix I--Towards a User-Based Motorist Information System for the Puget Sound Area: a State-of-the-Art Review.)

Methodologies for Motorist Surveys

For many years, transportation specialists have used survey results to guide highway design decisions; the most recent focus has been on motorist behavior, specifically from the framework of activity based driver analysis [1]. To improve and develop driver information systems in the Puget Sound area, we first needed to understand more about motorist activities and behaviors, particularly the potential for changing these behaviors through the design and delivery of motorist information. In the past, an understanding of motorist behavior has often been obtained through household based trip surveys or general driver population surveys. However, we desired a more direct approach. Therefore, we targeted commuters who use a specific freeway corridor and administered to them: (1) a large sample mail-in survey, distributed on-road, (2) a smaller sample, in-person survey, and (3) a testing and analysis of motorist information screens.

We began designing our survey by examining previous relevant research. A search to identify recent surveys administered on the issue of motorist behavior led us to focus on the methodology of 12 surveys conducted by public agencies or universities between 1963 and 1987, in Texas, California, Sweden, and England. All of the studies were administered in urban areas and had sample sizes ranging from 25 to 2,971. Our examination of these surveys helped us to identify important aspects of motorist survey methodology. Table 1 of the state-of-the-art-review (Appendix I, p. 4) overviews the methodologies of these surveys.

Given the great diversity in the designs and methods used in previous motorist surveys, numerous complex decisions had to be made during the survey design phase of our project. The state-of-the-art-review (Appendix I) examines issues related to these decisions which are not frequently discussed in the existing literature on motorist surveys. For example, our review of previous relevant research revealed that past statistical efforts have often been limited to descriptive analyses. However, statistically more powerful techniques are often required to achieve the goals of a motorist survey, and innovative application of these techniques can both enhance the internal validity of the design and increase the generalizability of the findings. Conclusions like this one were the major guides in our survey design. For this reason, we recommend that the following description of our survey methodology be read in light of the other relevant survey methodologies discussed in the first section of Appendix I.

In the end, the considerable effort put into survey design paid off. The primary goal of the first survey was to identify commuting characteristics of corridor drivers and their use of and preferences for motorist information; the primary goal of the in-person survey was to assess further details of motorists' daily activities related to their commute and preference for information design. Our approach to these surveys proved to be cost efficient, resulted in high response rates and large samples, and gathered complex and varied data which enabled us to achieve these goals.

Methodology of the FAME Motorist Information Survey

Throughout the design and development of the FAME Motorist Information Survey, we were careful to address considerations raised by our study based on previous motorist survey efforts. Survey methodology has a major impact on survey findings. For example, the choice of sample size involves tradeoffs: a small sample allows for extensive in-person questioning yet may restrict generalizability; in contrast, a large sample produces information that can be generalized, though the survey may be administered in a less personal way and may be restricted in the amount of information it seeks. In addition, the methods used to generate the sampling frame may depend on the desired sample size and methods of survey administration. In response to these considerations, we combined a large sample, mail-in survey with a smaller sample, in-person survey in an effort to maximize the strengths of each while minimizing the weaknesses.

Another example of how previous efforts affected our design came in the area of statistical analysis. Limits on statistical analyses are often imposed by the qualitative nature of the variables assessed. We determined to collect more quantitative data which would lend themselves to the use of inferential statistics. The following presents more specific information about our survey design and methodology.

Survey Respondents

The first steps in the project's design were to identify the survey population and sampling frame, and the actual sample.

Survey Population and Sample Frame

The goal in selecting the survey population was to identify a large number of Washington State freeway commuters who experience traffic congestion and who have access to various forms of traffic information. In response to this goal, two Seattle corridors were suggested: North/South I-5, East /West SR520, or East/West I-90. It was assumed that each freeway corridor would be unique in certain ways. These corridors were initially specified for three reasons: (1) these Seattle corridors have extremely large traffic volumes that would allow for obtaining a sizeable sample, (2) motorists who use these corridors during commuter rush hours frequently experience traffic congestion, and (3) these corridors contain various message delivery systems. The North I-5 corridor was finally selected because it contained the larger variety of motorist information delivery media, including two on-road traffic message delivery systems: Variable Message Signs (VMS) and Highway Advisory Radio (HAR). Based on the corridor selection, the population was narrowed to include all motorists who use I-5 to commute from the north into the greater Seattle downtown area.

From the population described above, a sample frame was selected that would provide a sufficient number of motorists to represent the population. To be included in the sample frame, motorists had to: (1) travel south on some portion of the North I-5 corridor to downtown Seattle during peak morning hours (5:45 am - 8:45 p.m.), (2) travel this corridor at least once a week, and (3) be the driver of a commuting vehicle. Based on WSDOT exit ramp data, approximately 25,000 drivers per day met these criteria.

Sample

We estimated that a minimum sample size of 500 would provide findings with sufficiently small standard errors to accurately represent the driving population for the selected highway corridor, provided that the selected sample truly represented the population. However, a secondary concern was to identify from this initial survey respondents who would be willing to participate in a follow-up in-depth survey (of whom about 150 would be randomly selected to participate). Therefore, it was necessary to start with a much larger initial sample size than the 500 minimum first suggested. Assuming that 25% of the total initial survey respondents were likely to volunteer for the in-depth survey, we realized that a minimum of about 2,000 respondents to the initial survey would be needed to assure the success of the follow-up survey. Further, we conservatively estimated a response rate for the mail-in survey of 20% (the actual rate was 40%), making the desired motorist sample almost 10,000 (the largest motorist survey of its kind).

Survey Administration

The following describes the methods used in administering this survey.

Survey Method

Five survey methods were evaluated. All methods were evaluated based on the following criteria: time frame for accessing motorists, potential response rate and/or bias, accuracy of contacting the desired sample frame, and time differential between time of commute and receipt of survey. The off ramp method would allow us to (1) access motorists easily and without much delay, (2) obtain a high response rate, (3) obtain a representative sample, and (4) reduce the time between motorists' commute and receipt of the survey. The five methods we evaluated are described in Appendix IIA.

Distribution and Collection Procedure

Two week-days in September 1988 were chosen for survey distribution and the eight off-ramps in downtown Seattle were randomly assigned as follows:

September 13: Mercer, Columbia and 5th(a), Columbia and 5th(b), Cherry and 6th.
September 14: Stewart, Union, Cherry and 5th, Dearborn.

Survey distribution times were based on peak hour data from WSDOT ramp figures. Rush hour (5:45 am - 8:45 am) was selected because it permitted direct access to motorists who were the target population. Each survey was stamped with a case ID number between 00,001 and 10,200 and each site was provided with a bundle of survey questionnaires equivalent to the expected rush hour traffic volume. The case IDs of the surveys assigned to each site were recorded so that the response rate per site could be tracked.

One survey administrator and 1-3 distributors appeared at each distribution site. They waited for traffic to stop at the first red light after the freeway exit and then proceeded to each driver and handed him or her a survey. The administrator or distributor then proceeded to the next vehicle in line and handed out the next survey. When the lights turned green, the administrators moved to the shoulder and waited for the next red light. In total, 9,652 surveys were distributed.

A statement on the survey requested that motorists return it by September 30, 1988. In addition, media coverage of the survey distribution was used to generate publicity to encourage motorists to fill out and return their questionnaires. The surveys, when folded and stapled or taped, displayed the Washington State Department of Transportation address and a postal permit number. The surveys were gathered by WSDOT and forwarded in batches to the University of Washington for processing. The daily rate of return was initially very high but decreased as the September 30, 1988, deadline approached. By November 4, 1988, 3,893 surveys had been returned. Any that arrived after this date were not processed.

Questionnaire Design

This section explains how the questionnaire was developed and how strategic objectives affected the development of the questionnaire. Appendix II shows the actual questionnaire, with some minor format adjustments to fit the size requirements of this publication.

Content

The content was based upon specific information needs of this study, an extensive review of other motorist surveys, analysis of human factors issues relevant to driving, and suggestions from WSDOT personnel. After numerous questions were designed by all relevant parties, the questions were grouped into four categories: (1) characteristics of the commute itself, (2) motorist choices and behavior, (3) delivery of traffic information, and (4) descriptive data for driver classification. Through discussion with WSDOT, a pre-test of 25 drivers, and elimination of questions (some of which became part of the in-depth follow-up survey), the final questions were selected and grouped. To provide the sample frame of volunteers for the follow-up survey, the questionnaire also provided a name, address, and telephone number section that was to be completed if the respondent would be available for a personal interview.

Layout and Form Decisions

The layout and physical form of the questionnaire were determined by the distribution/return methodology. Space was provided on the interior margins for respondents to add comments. To facilitate accurate data entry, response boxes or input lines were provided for each question. The survey was designed to be a three-fold self-mailer. (See Appendix II.)

Data Coding and Analysis

Before the surveys could be sent to data entry personnel, I-5 entrance/exit answers were recoded to obtain the number of miles for the respondents' commute to and from work. Where respondents were asked to report their average times to commute to and from work, research assistants averaged all range responses to obtain discrete data. Also, before the surveys were sent to data entry personnel, they were sorted into two major categories: those with comments and those without comments. Comments were categorized by traffic relevance and the traffic relevant comments were categorized as positive, neutral, or negative. All survey questionnaires with comments were sorted into two categories: those with comments relevant to the traffic study and those with comments not relevant to the traffic study. When the questionnaires were returned from the data entry personnel, they were sorted into two categories: those with addresses (willing to participate in follow-up survey), and those without addresses. This sorting was accomplished to facilitate the in-depth interviews.

The data were analyzed in SPSS-X on the Max Mainframe at the University of Washington. After frequencies were calculated for all variables for the total sample and the sample separated by gender, gender differences were assessed with t-tests for interval data and Mann-Whitney *U* tests for ordinal data. Next, Pearson correlations were applied to interval scaled data and Spearman correlations were applied to all ordinal and a few nominal scaled variables if the coding met the assumptions of the Spearman routine. A Factor analysis then was conducted on relevant variables. Finally, Cluster Analyses and Chi Squares within clusters were conducted to identify possible motorist groups and the significant differences between the groups' responses on specific questions.

Methodology of the In-Depth, Follow-up Survey

The initial survey provided an extensive amount of data on commuter behavior, described in the "Findings" section below. It revealed that the commuting population of the metropolitan Seattle area is complex, cannot be treated as a homogeneous audience for motorist information, yet is composed of stable sub-groups. However, it also raised a number of interesting questions. These questions were probed through a follow-up, in-depth interview. These included questions regarding flexibility in departure and arrival time, commuters' specific knowledge of primary and alternate routes, detailed knowledge of the characteristics of the commute, and preferences for graphical design of motorist information. The in-depth survey is discussed in two parts: Part 1 covering the commute and VMS messages, and Part 2 covering graphical display of motorist information for screen design.

Subjects

Subjects were selected from the 1,697 of 3,983 initial survey respondents who indicated their willingness to participate in an in-depth study. Subjects were selected so that the four clusters would be represented randomly yet proportionally. Subjects were contacted by telephone and were scheduled for a specific interview time at the University of Washington. A total of 120 subjects were recruited and a total of 96 subjects participated in the study. Thus, the study showed an 80% response rate.

Part 1 Methodology

Identification of Dependent Variables

The in-depth interview probed four broad areas of interest, based on the analysis of responses to the initial survey: (1) the behavior and decisions of commuters relative to choice of commute route prior to departure; (2) the behavior and decisions of commuters while driving; and

(3) the responses of commuters to a set of syntactic and semantic manipulations of messages that might be displayed on highway variable message signs (VMS) and (4) preference for different graphical forms of traffic information. Additional questions were included to broaden the knowledge of the demographics of the sample.

The survey was limited in temporal scope to the in-bound commute. This decision was partially driven by the observation of significant differences in commuters' flexibility in departure on the morning commute with fewer differences observed for the afternoon commute (see "Findings" below). Also, the literature on survey methods (e.g., [2]) indicates that total in-person interview time should be less than one hour for all aspects of the interview; therefore it was seen as infeasible to probe both inbound and outbound commutes and obtain commuter responses to simulated displays of traffic information.

There were four major sets of survey questions. The first set of questions investigated the behavior of and decisions made by commuters in the period prior to their departure for work. To understand the environment in which pre-trip traffic information is received and used, it was necessary to probe the amount of time that commuters have prior to departure and the number and type of demands experienced by commuters prior to departure. Commuters were asked to estimate the time they normally awaken and the time they normally leave for work; these estimates were used to calculate the average amount of time that commuters have prior to departure. Commuters were also asked to estimate the number of significant tasks they complete during this period; significant tasks were defined as any tasks outside of those tasks completed in order to prepare for departure. Commuters were also asked to give subjective estimates of the amount of stress they experience during the period prior to their departure and of the amount of flexibility they perceive in their departure time.

The first set of items also included questions probing the access to and use of traffic information during the period prior to departure. Commuters were asked to describe how actively they seek traffic information, how frequently they receive traffic information, and the decisions they normally would make based on that information. Commuters also estimated the amount of time between first receiving information and their departure time. Commuters were then asked about their decisions to alter choice of route, mode, and departure time.

The second set of survey questions probed commuters' behavior and decisions on their commute from home to work. Subjects were asked to give verbal descriptions of their primary route and one or two alternate routes (if known and used); they were also asked to trace those routes on maps provided by WSDOT. Commuters' knowledge of those routes was assessed by counting the number of landmarks, street names, and compass directions used in the verbal descriptions of primary and alternate routes, a method suggested from human-factors investigations in route knowledge, navigational skills, and map reading ([3]; [4]).

Tallies were made of the total number of decision points on the primary and alternate routes; decision points were defined as points where drivers might need to make adjustments to their routes. Commuters were asked to report their reasons for altering routes at each of the decision points, and their use of and response to traffic information (including their own subjective observations of traffic conditions) in making their choices at each of the decision points. Additional questions probed sources of information used to either confirm or refute decisions to alter routes. The final items in this set of questions probed commuters' perceptions of stress if they chose to use alternate routes, perceived flexibility in arrival time, and perceived penalties for arriving late. Commuters were also asked to estimate the number of times they arrived late each month due to traffic conditions.

The third set of questions probed commuters responses to syntactic and semantic manipulations of messages that might be displayed on variable message signs (VMS). Two messages actually displayed by the WSDOT on a VMS located above south-bound I-5 at the ship canal bridge were used as the basis for two sets of manipulations.

The first set of manipulations involved the "type of task" presented in the message and the order in which the task was presented, both variables known to affect performance. Two types of tasks were presented, specific and generic. Messages that presented specific tasks suggested a specific alternate route in response to a traffic situation (e.g., "Use I-90 Eastbound"); messages that presented generic tasks suggested a general response to a traffic situation (e.g., "Use alternate routes"). The order of the messages was manipulated so that the task (either generic or specific) appeared either before or after the reason (the description of the traffic problem).

The second set of manipulations involved the type of reason presented in the message and the presence or absence of the task (the response to the traffic situation). Two types of reasons were presented, specific and generic. Messages that contained specific reasons presented a specific description of the traffic problem (e.g., "Accident at Mercer Street exit"); messages that presented generic reasons presented a more general description of the traffic problem (e.g., "Accident ahead"). The messages were also manipulated to present either a suggested response to the traffic situation or a general statement (e.g., "Expect delays").

A final set of questions in the survey portion were intended to provide information that was not obtained in the initial survey and was desired in order to get more detailed information on the demographics of the sample population. Items in this final set of questions probed marital status, the number of adults contributing to household income, and the number and ages of children (if any) in the home.

Survey Administration: Initial Considerations

Our choice of survey administration method considered a number of issues: demands placed on the subject, subject reinforcement, reliability, response mode, and tone and presentation. The in-person interview format was selected based on a review of the literature and after considering the issues surrounding the types of questions to be asked. A number of authors (e.g., [2]; [5]) have suggested that as demands placed on the respondent are reduced the quality of responses increases. Babbie (1989) notes that not only do in-person interviews have higher response rates than other survey methods, in-person interviews also allow the interviewer to clarify questions when the respondent is confused. Additionally, in-person interviews allow a wider set of responses to items in the survey.

In-person interviews allow subjects to be positively reinforced for their participation, both at the outset and at the finish of the interview, thus increasing subjects' sense of the importance of their contribution to the survey. Finally, Sharp and Frankel (1983) note that if subjects perceive their contribution to be important their responses will be of higher quality.

A major problem with in-person interviews stems from the lack of reliability that can be imposed on the data due to inconsistencies between interviewers and between the interview sessions conducted by individual interviewers. In the present study, two steps were taken to control for these two threats to reliability. First, interviewers were trained by a single trainer and were required to meet specific criteria before being allowed to interview commuters. Second, interviewers worked from a written questionnaire format that specified all interviewer prompts and provided a set of categories for recording commuter responses.

The formal training of interviewers occurred in two parts. The first part of the training consisted of the trainer reading each of the questions as they should be read to commuters and discussing the possible responses. During this first part of the training, the trainer also discussed issues of timing and preparation for the interview. The second part of the training required the trainee to interview the trainer. The trainer was prepared with a set of difficult or ambiguous responses to a number of the interview questions. The trainee was required to respond to and code the responses correctly two times without error before being considered trained on a specific question. Each interviewer received approximately three hours of direct training prior to being allowed to interview commuters. In addition, each interviewer was required to have partially memorized the scripted portions of the interview prior to the formal training. Once trained, interviewers were debriefed by the trainer following randomly selected interviews to determine if any additional training was needed (it wasn't).

Use of the in-person interview format allowed commuters' response to VMS messages to be accurately timed, data that would not have been obtainable in other formats. The in-person format also allowed interviewers to observe commuters tracing their primary and alternate routes and make tallies of decision points as well as landmarks, street names, and compass directions used in verbal descriptions of commuting routes.

The tone of the interview was intended to be conversational but neutral. Interviewers were to present themselves as interested professionals in order to enhance commuters' sense of the importance of their responses without encouraging specific response patterns.

Survey Administration: Conduct of the Interview

Interviews were administered at the University of Washington. The interviewer introduced him- or herself to the subject and asked the subject to fill out a University of Washington subject's voluntary consent form. The interviewer then read the subject a short introduction, giving the subject an overview of the types of questions he or she would be asked to answer, and the length of the interview. The subject was informed that his or her participation was voluntary and that, at any time, he or she could take a break or terminate the interview. At the end of the interview, the subject was told that he or she could contact the study investigators if he or she had any further questions. Subjects were not paid for their participation; however, parking fees (for parking on campus) were reimbursed at the time of the interview.

Data Coding and Analysis

All categorical variables were coded for data entry following completion of the entire set of interviews. A standardized coding protocol was established, assigning numeric codes to the categories of responses in each of the interview questions. Coding of all interviews was completed by two research assistants. The reliability of their coding was subsequently checked and all errors were corrected prior to data entry. Once all interviews were coded the codes were transferred to data entry sheets to allow for faster entry of the data. Data were entered into a numeric data file and were later checked and all entry errors corrected.

All statistical analyses were conducted using SYSTAT, statistical software written for the IBM PC and compatibles. The software was installed on an IBM PC equipped with 1 megabyte of internal storage and a 30 megabyte hard drive. Descriptive statistics (means and standard deviations) were calculated for all continuous variables and tabulations were obtained for all categorical variables. All continuous variables were subjected to analyses of variance (ANOVAs), with grouping factors being cluster membership (see below) and categories of miles travelled on I-5. Responses to the VMS manipulations were subjected to repeated measures analysis of variance

[6]. All categorical variables were subjected to Kruskal-Wallis non-parametric analyses of variance with grouping factors being cluster membership and categories of miles travelled on I-5.

Part 2 Methodology

Questions Related to Dependent Variables

This portion of the second survey was developed in an effort to determine whether different clusters have a preference for different graphical forms of traffic information. The traffic information was displayed as "screens," simulating at-home delivery on television screens. Subjects were required to evaluate screens of simulated traffic information by filling out a questionnaire.

The literature review indicated that time and distance were critical variables for commuters. Influences of weather and parking conditions were also investigated. Five different general forms of traffic information were combined to produce several graphic screens: bar graphs, maps, text messages, photographs of actual traffic, and travel time estimates. There were two main sections to the questionnaire, an individual screens section and a general "all screens" section.

The individual screens section asked a parallel set of questions about commuter behavior in response to the screens. Two questions were asked about each screen. The first question addressed the subject's behavior. Commuters about to leave home can modify their behavior in three ways; they can delay departure, choose an alternate route, or change mode of transportation. The first question asked what specific choices a subject would make based on the screen. The second question in the individual screen section asked the subject to indicate which form of information influenced the choices.

The "all screens" section included general questions pertaining to all screens, and specific questions addressing screen design. Each question will be discussed in order.

The first question asked the subject to indicate the ONE screen that was most helpful in planning a commute. The subject was asked to rank order all the "forms" of information provided (i.e. bar graphs, photographs) as to how helpful they were. A significant difference in answers to this question across clusters might indicate that different traffic information screens could be designed for individual clusters.

The subject was next asked his or her preference for map orientation. This question tested the hypothesis that individuals commuting from north to south may prefer the vertically oriented map of I-5, while east to west commuters may prefer the horizontal. The traffic map was presented in each orientation in the screens section of the questionnaire and subjects were asked which orientation they preferred.

Each subject was next asked which landmarks they typically use for travel time estimates. Subjects were provided with examples such as "Northgate Mall." This question was asked to determine which landmarks would be the most useful for drivers as physical reference points on traffic screens.

Subjects were next asked if they would use a television based information service like the one they had just seen. In the initial survey 73.4% of the subjects stated that they would NOT use a continual up-to-the-minute traffic information service delivered via cable TV. The question was repeated to see if they would respond the same after seeing examples of potential screens. Subjects who said they would use a TV-based service were asked which time during the day they would most prefer to receive traffic information.

Graphics Questionnaire Design and Use

Subjects evaluated hard copy representations of television screens containing different kinds of graphical traffic information. The questionnaire was designed to test screen design issues and to determine preferences for different forms of traffic information. The questionnaire was also designed to test whether there were different preferences for information across clusters.

The graphics questionnaire had two main sections, an individual screen section and a general section with questions about all of the screens. The individual screen section asked commuters to express choices they would make based on the information each screen provided. In the second "all screen" section, subjects were asked about their delay time, route choice and mode choice.

Three different responses were elicited from the subjects. Subjects were asked to check options, to fill in blanks, or to rank responses on a 5 point scale.

A pilot test was conducted to identify deficiencies in the questionnaire and to estimate the time required to complete it. Based on the pilot test and the need to limit total interview time to less than one hour, a time limit of 15 minutes was placed on the administration of the graphics questionnaire. Because of this restraint, the questionnaire was limited to four sections, each devoted to a different screen of information, in addition to the general "all screen" section.

The tone of the questionnaire was kept conversational yet concise. Questions were designed so that subjects could respond to them clearly and quickly. The subject was first provided with a scenario with which to evaluate the screens. The subject was provided with a questionnaire and a binder containing the simulated screens of traffic information, and instructed to begin. Any questions the subject had during the questionnaire were answered by the administrator.

After the subject completed the questionnaire, the administrator checked the questionnaire for completeness and accuracy and reviewed any mistakes with the subject. The administrator recorded the time the subject took to complete the questionnaire and thanked the subject.

The questionnaire was administered immediately following Part 1 of the interview in a class room at the Mechanical Engineering building as well as in offices at Loew Hall at the University of Washington. The data was entered into a statistical package directly from the questionnaire. Only one error was found after data entry, and it was not corrected. Statistical analysis was performed on the University of Washington VAX 8650. The statistical software used was SAS, version SAS-518.

Conclusion

Our approach to gaining an understanding of commuter information needs was carefully developed, applied, and refined over the course of the project. In the past, motorist behavior had primarily been studied through household based trip surveys. This was particularly true in the Seattle area. Our approach, however, was to use a commuter-based survey of a general population with a follow-up in-depth survey of a selected segment of that population. This method proved to be more cost efficient ($29 per car vs. $59 per household), resulted in a higher response rate (41% vs. 35%), and gathered more complex and varied data when compared to recent household surveys conducted by the Puget Sound Council of Government. In addition, we have subjected our data to more sophisticated statistical analyses than have been previously applied to traffic data.

In fact, one side outcome of our work is the development of a successful survey methodology for studying motorist behavior and information needs. It is likely that considerable benefits could be obtained by applying this methodology to other situations. Certainly it would be advisable to extend our survey of commuter behavior and traffic information beyond the north I-5 corridor of Seattle to the rest of the Puget Sound area. By studying the two remaining freeway corridors, the Seattle inbound commuters on the southern I-5 corridor, and the east/west commuters on the I-90 and SR520 corridors, and by using the survey methodology and instrument developed in our initial work so as to assure comparable data, we could produce a complete analysis of Seattle metropolitan commuter behavior and design requirements for a comprehensive Puget Sound motorist information system.

FINDINGS

Findings are presented in three sections: (1) results from the initial survey, excluding cluster analysis; (2) results from the cluster analysis; and (3) results from the in-depth, follow-up survey.

INITIAL SURVEY RESULTS (EXCLUDING CLUSTER ANALYSIS)

The following results are grouped similarly to the major sections of the original survey (see Appendix II): (1) commute characteristics; (2) motorists' choice of route; (3) delivery media for traffic information, and (4) demographic data. However, the order of the survey questions has been adjusted for discussion purposes. So as not to overburden the reader, some detailed statistics are discussed in general terms in the text and then further detailed in tables. Furthermore, male and female response categories are presented only when significant gender difference occurred. As variable numbers and names are referred to in various tables throughout this results section, a complete list of variable numbers and names is presented in Appendix III. As expected, due to the large sample size, numerous correlations were found to be significant at the $p \leq .01$ and $p \leq .001$ level; as many correlations would be statistically significant yet have no constructive value, we arbitrarily decided for the purpose of this discussion to focus only on those correlations that accounted for a minimum of 9% of the variance (i.e., r values $\geq .30$ or $\leq -.30$) Complete Pearson and Spearman correlation matrices are found in Appendix IV.

Commute Characteristics

Commute characteristics are examined in two general areas: the situational aspects of the commute, and motorists' attributes.

Situational Aspects

This subsection discusses the survey results on commute frequency, vehicle occupancy, distance, and time duration of motorists' commute on I-5 from the north to downtown Seattle and back again after work. Most surveyed motorists commuted to work 5 days per week (66.5%) with the next highest number of days per week being 6 days per week (8.5%). Five other response categories (1-4 and 7 days per week) each received about 3% of the responses: 9% of the motorists stated they commuted zero days per week (i.e. were not in our sample frame). A t-test assessed gender differences on this variable and revealed that males and females commute a similar number of days per week.

Most motorists (75.0%) who completed the survey travel alone in their cars; however, 18.6% of motorists travel with one other person in their car. They use I-5 (southbound and northbound) for an average of 8.5 miles of their commute. The reported northbound and southbound distances are quite similar and significantly correlate with each other, $r = .94, p \leq .001$. On this freeway corridor, commuters average distance between home and work is 14.9 miles. This distance is traveled during the morning commute in about 31 minutes and during the evening commute in about 35 minutes. A Pearson correlation revealed that the distance between home and work significantly correlates with traveling time between home and work, $r = .81, p \leq .001$ and with traveling time between work and home, $r = .76, p \leq .001$. As expected, traveling time between work and home and between home and work significantly correlated with each other, $r = .86, p \leq .001$. T-tests of gender differences on these three variables revealed that females' homes are located significantly closer to work (M = 14.34 miles, SD = *8.31*) than males (M = 15.36, SD = 10.29 miles), $t = 3.14, p \leq .002$. This finding agrees with that of numerous other traffic surveys. Interestingly, while males travel a significantly greater distance to work than females, no significant difference exists in the time that both genders require to travel their respective distances. This suggests that females drive slower than males, or in greater congestion.

In summary, for this I-5 corridor, most motorists appear to commute alone 5 days a week, travel about 15 miles to work with about 8.5 miles of this total distance driven on I-5, and spend about 31-35 minutes for their entire commute. While females live slightly closer to work than males, their commute time is similar to that of males.

Motorists' Attributes

This section examines motorists' responses regarding flexibility in time leaving home and work, perceived stress during the commute, and importance of selected commute qualities. As shown in Figure 1, twice as many motorists (29%) have a lot of flexibility in the time that they leave work for home than the time that they leave home for work (13% stating a lot of flexibility). A Spearman correlation revealed that the flexibility in the time leaving work positively correlates with the flexibility in the time leaving home, $r_S = .42, p \leq .001$. A Mann-Whitney U test revealed that females were significantly younger than males in the sample and had significantly lower mean incomes. A Mann-Whitney U test revealed that males are more flexible than females in the times they leave home or work, $p \geq .001$. (See Table 1 for complete Mann-Whitney results.) The reasons for this were assessed in the in-depth follow-up survey.

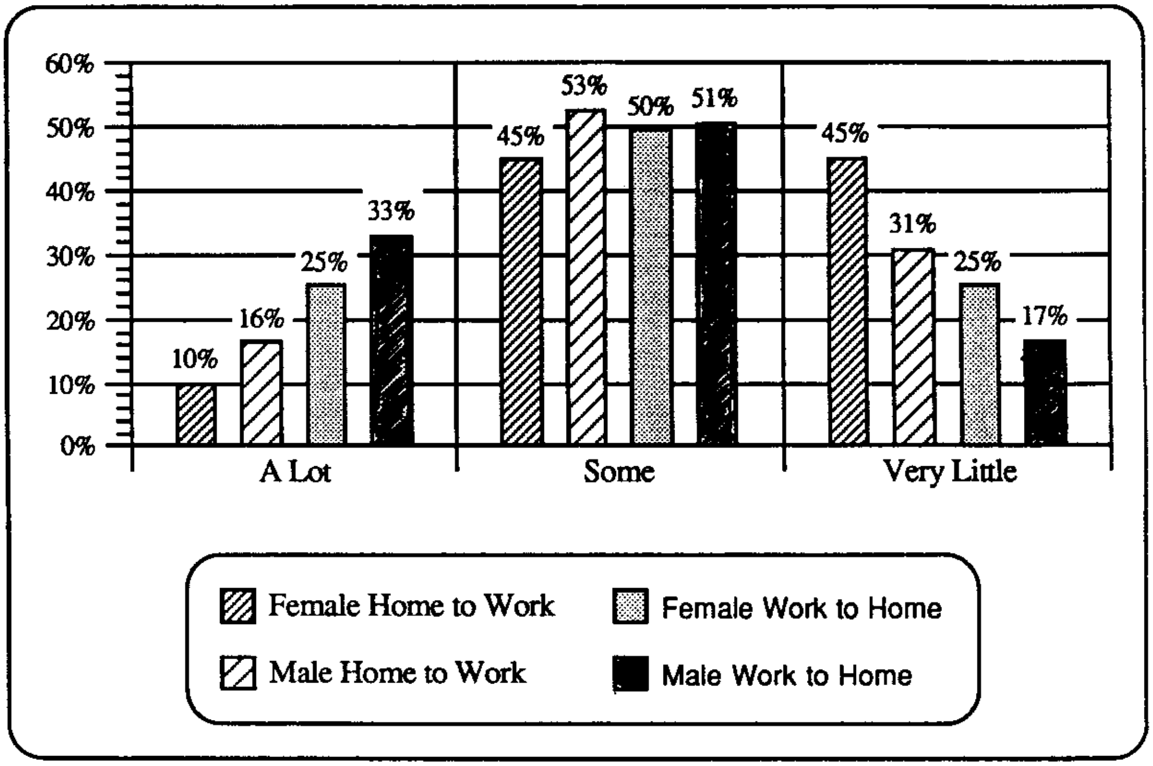

Figure 1. Flexibility in the Time Motorists Leave Home and Work.

Most motorists (57.6%) experience some stress during their commute; 14.8% experience a lot of stress and 26.4% experience very little (see Figure 2). However, a Mann Whitney *U* test for gender differences on this variable revealed that females experience more stress during their commute than males, $p \leq .001$. This result is interesting in light of the lower flexibility that females report they have in the time they leave either home or work as stated above and as shown in Figure 2.

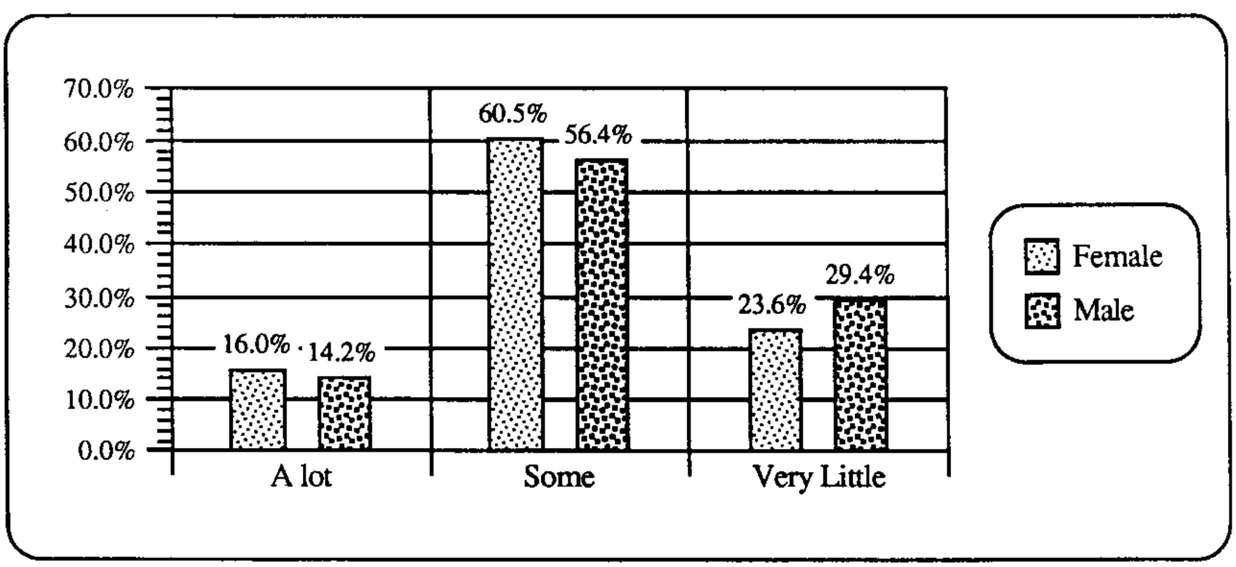

Figure 2. Stress Experienced During Commute

Table 1. Significant Mann-Whitney Results

	Variable Number and Name	Mann-Whitney *U*	Z	2-tail *p*	N[1]	Females[2]	Males[3]
7	Flexibility in time leaving home for work	1258190	-9.49	.0000	3481	1590.8	1884.9
8	Flexibility in time leaving work for home	1299329	-6.91	.0000	3447	1614.0	1828.8
9	Stress during commute	1379152	-4.04	.0001	3446	1785.4	1663.7
10	Impt. saving commute time	1369325	-5.63	.0000	3472	1817.0	1659.3
11	Impt. reducing commute distance	1254639	-7.31	.0000	3405	1819.5	1591.6
12	Impt. increasing commute safety	1285955	-7.87	.0000	3455	1849.5	1611.4
13	Impt. increasing commute enjoyment	1366830	-3.80	.0001	3429	1776.0	1656.8
15	Familiarity with alt. N/S rtes	1235070	-11.38	.0000	3492	1577.8	1908.5
16	Frequency of changing rte. to work	1388084	-5.37	.0000	3492	1667.3	1822.6
21	Weather affecting commuting rte.	1401377	-4.46	.0000	3481	1807.1	1677.7
22	Time pressure affecting commuting rte.	1358866	-5.80	.0000	3481	1832.1	1653.8
26	Receive traffic info. via TV	1734548	-3.10	.0020	3814	1951.9	1864.7
27	Receive traffic info. via VMS	1664103	-5.19	.0000	3813	1988.6	1828.4
29	Receive traffic info. via commercial radio	1739104	-2.77	.0055	3815	1950.5	1867.0
31	Receive traffic info. via CB	1774917	-4.29	.0000	3814	1884.6	1929.5
32	Never receive traffic info.	1773658	-3.88	.0001	3814	1884.0	1930.2
35	Helpfulness of TV traffic info.	1265036	-2.85	.0044	3266	1675.3	1591.6
36	Helpfulness of VMS traffic info.	1235607	-5.83	.0000	3332	1758.6	1576.0
41	Before driving, traffic info influences time leaving	1493789	-9.02	.0000	3771	2039.1	1738.6
42	Before driving, traffic info. influences mode choice	1433832	-6.80	.0000	3601	1907.1	1700.5
43	Before driving, traffic info. influences rte. choice	1665913	-2.59	.0095	3737	1912.2	1827.7
45	Anticipated use of phone hot line for traffic info.	1295392	-6.67	.0000	3409	1798.5	1614.3
48	Anticipated use of cable TV for traffic info.	1341797	-2.96	.0031	3352	1714.2	1639.5
50	Availability of radio in home, office, car	1663491	-4.99	.0000	3813	1825.1	1986.0
58	Age	1417551	-12.26	.0000	3813	1693.6	2112.6
59	Household income	1258700	-12.56	.0000	3637	1597.4	2112.6

Notes

N[1] = Number of cases responding to the question
Females[2] = Mean Rank sums presented for Mann-Whitney *U* statistics
Male[3] = Mean Rank sums presented for Mann-Whitney *U* statistics

When asked about the importance they placed on various commuting qualities, most respondents (66.8%) believed that saving commute time was very important; half of the motorists believed that increasing commuting safety was very important; roughly a third believed that increasing commute enjoyment was very important; they placed the least importance on reducing commuting distance. A Spearman correlation revealed that those motorists who valued commute safety also valued commute enjoyment, $r_s = .35, p \leq .001$. A Mann-Whitney *U* test for gender differences on these four commuting qualities revealed that females place more importance on all four commuting qualities than males, $p \leq .001$. (See Table 2.)

Table 2. Importance Placed on Commuting Qualities

Saving commute time:	A lot	Some	Very little
Both	66.8%	28.8%	4.3%
Female	71.2%	25.3%	3.5%
Male	62.6%	32.2%	5.2%
Reducing commute distance:			
Both	17.7%	38.6%	43.6%
Female	20.1%	41.5%	37.7%
Male	14.6%	35.9%	49.4%
Increasing commute safety:			
Both	54.4%	35.6%	9.8%
Female	60.6%	33.3%	6.11%
Male	48.9%	37.9%	13.1%
Increasing commute enjoyment:			
Both	37.5%	43.0%	19.4%
Female	39.9%	43.1%	17.0%
Male	35.2%	43.3%	21.6%

In summary, a number of generalizations can be drawn about the quality of motorists' commutes. First, motorists have greater flexibility as to the time they leave work for home than the time they leave home for work; in addition, males have greater flexibility in the time they leave either home or work than females. Most motorists experience some stress during their commute, with females experiencing greater stress than males. Motorists place the greatest value on saving commute time, with females valuing commute qualities (time saved, increased safety, increased enjoyment, and reduced distance) more than males.

Route Choices

When asked about their familiarity with northbound and southbound alternatives to I-5, 62.3% of motorists believed that they were very familiar with alternate routes. (See Table 3.) A Mann-Whitney U test for gender differences revealed that males claim to be more familiar with alternate routes than females, $p \leq .001$.

Table 3. Familiarity with Northbound and Southbound Alternatives to I-5

	Very	Somewhat	Not at all
Both	62.3%	32.8%	4.8%
Female	53.5%	40.2%	6.4%
Male	71.3%	25.5%	3.2%

Motorists modify their routes from home to work less frequently than they modify their routes from work to home: 63.1% of motorists rarely change routes between home and work, as opposed to only 42.2% who state that they rarely change routes between work and home. (See Table 4.) Responses to these two issues positively correlate, $r_S = .41, p \leq .001$. A Mann-Whitney *U* test for gender differences revealed that males are more likely to modify their route between home and work than are females, $p \leq .001$. One should recall that males had greater flexibility in the time they could leave home or work than females.

Table 4. Frequency of Modifying or Changing Commuting Route

		Frequently	Sometimes	Rarely
Home to work:	Both	6.1%	30.7%	63.1%
	Female	5.2%	27.4%	67.4%
	Male	7.0%	34.1%	58.9%
Work to home:	Both	14.3%	43.5%	42.2%
	Female	13.7%	43.1%	43.2%
	Male	14.8%	44.0%	41.2%

When asked what length of delay would cause motorists to divert from I-5, the average response was 16.3 minutes to routes they know, and 25.5 minutes to routes they do not know. As expected, these two variables (length of delay causing diversion to known versus unknown routes) significantly correlate, $r = .79, p \leq .001$. The amount of delay that causes motorists to switch to a known alternate route (M = 16.3 minutes, SD = 10.80) or an unknown route (M = 25.5 minutes, SD = 15.5) inversely correlates with the likelihood of changing route between work and home, $r_S = -.3.1, p \leq .001$ / $r_S = -.25, p \leq .001$, respectively. Motorists most willing to change routes will do so with shorter traffic delays than motorists less willing to change. T-tests revealed that males will divert to known routes (M = 15.8 minutes, SD = 10.4) sooner than females (M = 16.9 minutes, SD = 11.3), t =3.10, $p \leq .002$; additionally, males will divert sooner to unknown routes (M = 24.4 minutes, SD = 15.2) than females (M = 26.8 minutes, SD = 15.9), t =3.98, $p \leq .001$.

When motorists were asked where they choose their commuting routes, 33.8% stated that they made this choice while still at home or work; 23.0% chose on city streets, 25.6% chose near entrance ramps, while only 15.7% chose after entering I-5. When asked about the influence of five environmental factors on their choice of commuting routes, about one fourth of the motorists reported that traffic messages, traffic congestion, and time of day frequently influence their choices while only 8% believed weather conditions influence their choice of commuting routes and only 12% believe that time pressures have an influence. (See Table 5.) Other surveys have also found traffic congestion to influence drivers' decisions [4,6]; however, while only 12% of this survey's motorists stated that time pressures influence their commuting routes, other surveys have reported a strong effect of time pressure [4,12]. Mann Whitney U tests for gender differences on these five environmental factors revealed that females are more frequently influenced in their choice of commuting routes by weather conditions and time pressures than are males, $p \leq .001$.

Table 5. Environmental Factors Affecting Choice of Commuting Routes

		Frequently	Sometimes	Rarely
Traffic reports and messages:	Both	28.0%	48.1%	23.9%
	Female	28.4%	48.4%	23.2%
	Male	27.9%	47.5%	24.6%
Actual traffic congestion:	Both	28.6%	50.0%	21.4%
	Female	30.2%	48.5%	21.3%
	Male	27.3%	51.5%	21.2%
Time of day:	Both	23.4%	37.7%	38.9%
	Female	23.9%	37.6%	38.5%
	Male	23.1%	37.3%	39.6%
Weather conditions:	Both	8.0%	28.9%	63.1%
	Female	9.5%	30.7%	59.8%
	Male	6.8%	26.6%	66.6%
Time pressures:	Both	12.7%	35.5%	51.8%
	Female	15.8%	36.5%	47.7%
	Male	10.0%	34.3%	55.7%

When Spearman correlations were run on these five variables with each other and with frequency of changing route, all correlations were significant at $p \leq .001$. In Table 6 below, the first two columns show that motorists who do change their routes are affected by all five environmental factors. Interestingly, the influence of traffic information correlates most strongly with congestion, congestion correlates most strongly with time of day, time of day correlates strongly with weather and time pressure, and weather also correlates strongly with time pressure.

Table 6. Spearman Correlation Matrix of Selected Variables
(All correlations below are significant at $P \leq .001$.)

	Variable numbers and names *	16	17	18	19	20	21	22
16	Freq. of changing route to work	--						
17	Freq. of changing route. to home	.41	--					
18	Freq. of traffic info. affecting route. choice	.31	.26	--				
19	Freq. of traffic congestion affecting route. choice	.32	.38	.40	--			
20	Freq. of time of day affecting commuting route.	.28	.34	.26	.41	--		
21	Freq. of weather affecting commuting route.	.22	.20	.27	.29	.40	--	
22	Freq of time pressure affecting commuting route.	.23	.24	.27	.39	.47	.40	--

* Refer to Appendix III for a complete list of variables.

A number of generalizations can be drawn about motorists' route choices. Motorists are more likely to change their routes from work to home than from home to work, with males being more likely to change than females. Route changes are most influenced by traffic information, congestion, and time of day. Motorists will divert to known routes sooner than to unknown routes, and males will divert sooner than females.

Traffic Information

Survey respondents were queried about the influence of and their preference for the timing and location of traffic information as well as their use and preference for obtaining traffic information from different media.

Influence of and Preference for Timing of Traffic Information

When asked about their preference for time and place to receive traffic information, half of the motorists (53.2%) responded that they prefer to receive traffic information before driving. Almost 40% prefer to receive traffic information after beginning their commute, but before entering I-5 (22.4% preferred "city streets," 15.9% preferred "near entrance ramps"). Motorists least prefer to receive traffic information after entering I-5 (only 3.8% said they preferred receiving information on I-5). A 1971 Texas survey [7] also found that drivers prefer to receive traffic information before entering the freeway.

Depending on the driving decision, between 2% and 14% of motorists stated they are frequently influenced by traffic information before they drive. The data, as shown in Table 7, suggest that route choice and time for leaving are more influenceable than transportation mode; additionally, the influence of traffic information on pre-trip route choice and departure time significantly correlates, ($r_S = .47, p \leq .001$). Further, motorists who said that their route choice was influenced before driving also responded on an earlier question that their route choice was influenced by traffic information in general, $r_S = .47, p \leq .001$. The reported influence of traffic information on departure time also correlates with the influence on transportation mode, $r_S = .33$, $p \leq .001$. A Mann-Whitney U test revealed that traffic information influences females pre-trip decisions about departure time, transportation mode and route choice more than males, $p \leq .001$. This and data indicating a greater pre-trip flexibility by females (Table 7.), has lead us to believe that females reluctance to alter routes while driving may be due to a greater pre-trip attention to commuter choices, and therefore a greater commitment to the selected route.

For 52.4% of motorists en route, traffic information frequently or sometimes causes them to divert to an alternate route. Spearman correlations revealed that motorists who divert en route because of traffic information are also influenced by traffic information before they drive, $r_S = .46$, $p \leq .001$; motorists who said that their route choice was influenced while they were en route also replied to an earlier question that their route choice was influenced by traffic information in general and by actual traffic congestion, $r_S = .44, p \leq .001$, and $r_S = .39, p \leq .001$, respectively.

Table 7. Factors Influenced by Traffic Information Before the Commute

	Frequently	Sometimes	Rarely	Never receive
The time you leave				
Both	13.5%	43.1%	32.1%	11.3%
Female	16.8%	46.8%	27.4%	9.0%
Male	10.5%	39.4%	36.7%	13.4%
Your means of transportation (e.g., car, bus)				
Both	1.9%	5.7%	57.4%	35.0%
Female	2.4%	7.6%	59.8%	30.2%
Male	1.3%	4.2%	55.1%	39.4%
Your route choice				
Both	12.7%	49.0%	29.2%	9.1%
Female	13.4%	49.8%	29.8%	7.0%
Male	12.3%	47.8%	28.8%	11.1%

Preference for Traffic Information from Different Media

When asked about the sources of traffic information that they used, 97.6% of the motorists responded that they had used commercial radio before driving, during driving, or both. The second most popular source for receiving traffic information was the electronic message signs over I-5 (53.1%), followed by Highway Advisory Radio (43.6%), TV reports (29.4%), phone (7.5%), and CB radios (3.9%). Spearman correlations revealed that motorists who use electronic message signs over I-5 also use Highway Advisory Radio (HAR), ($r_S = .43, p \leq .001$); finally, motorists who use HAR also get traffic information over the phone ($r_S = .58, p = \leq .001$). Motorists who use TV to obtain traffic information also use HAR, ($r_S = .79, p \leq .001$) and commercial radio stations, ($r_S = .54, p = \leq .001$). A Mann-Whitney *U* test for gender differences revealed that females are more likely than males to receive traffic information from TV, electronic message signs over I-5, and commercial radio stations, while males were more likely than females to receive traffic information from CB radios. (See Table 8 for complete data).

Table 8. Sources of Traffic Information Used

	None	Before & While Driving	Before Driving	While Driving
TV:				
Both	70.6%	----	29.4%	----
Female	68.2%	----	31.8%	----
Male	73.0%	----	27.%	----
Electronic message sign over I-5:				
Both	46.9%	----	----	53.1%
Female	42.7%	----	----	57.3%
Male	51.0%	----	----	49.1%
Advisory radio indicated by flashing lights on highway sign:				
Both	56.4%	----	----	43.6%
Female	56.0%	----	----	44.0%
Male	57.1%	----	----	42.9%
Commercial radio station:				
Both	2.4%	64.5%	6.0%	27.1%
Female	2.7%	66.5%	6.4%	24.4%
Male	2.3%	62.5%	5.6%	29.6%
Phone:				
Both	92.5%	0.4%	6.1%	1.0%
Female	92.3%	0.3%	7.0%	0.6%
Male	92.7%	0.6%	5.2%	1.5%
CB Radio:				
Both	97.0%	0.4%	0.2%	2.4%
Female	98.3%	0.2%	0.2%	1.3%
Male	96.0%	0.5%	0.2%	3.3%
None:				
Both	96.2%	0.7%	2.7%	0.4%
Female	97.3%	0.6%	1.8%	0.3%
Male	95.0%	0.8%	3.7%	0.5%

Traffic information received from commercial radio stations was considered very helpful by 54.6% of the motorists surveyed, as compared to 7.1% who thought that electronic message signs over I-5 were very helpful, 5.1% for HAR, 3.3% for TV, and 0.5% for telephone highway construction hot lines. (See Table 10.) Spearman correlations revealed that motorists who found the electronic message signs over I-5 helpful also found HAR helpful, $r_S = .44, p \leq .001$; motorists who found traffic information delivered by commercial radio station helpful also stated on a later question that traffic information frequently causes them to divert to alternate routes, $r_S = .31, p \leq .001$. Finally, motorists who found commercial radio station information helpful state that they would use an up-to-the-minute traffic information phone line if it were available, ($r_S = .45, p \leq .001$), perhaps suggesting that a specific group of motorists prefer to receive information in an auditory mode as opposed to a visual mode. A Mann-Whitney U test for gender differences revealed that females, more than males, find both TV and electronic message signs helpful, ($p \leq .001$), perhaps implying that females find visual media more helpful than males.

Table 9. Rated Helpfulness of Traffic Information Sources

	A lot	Some	Very little	Never used
TV:				
Both	3.3%	15.1%	24.2%	57.4%
Female	4.6%	17.6%	21.8%	56.0%
Male	2.0%	13.0%	26.6%	58.4%
Electronic message sign over I-5:				
Both	7.1%	28.4%	44.3%	20.2%
Female	9.4%	30.4%	42.3%	17.9%
Male	4.8%	26.5%	46.6%	22.1%
Advisory radio indicated by highway sign:				
Both	5.3%	24.7%	37.7%	32.3%
Female	5.7%	25.1%	35.1%	34.1%
Male	4.5%	24.3%	40.4%	30.8%
Commercial radio station:				
Both	54.8%	35.3%	8.6%	1.3%
Female	55.9%	34.8%	7.8%	1.5%
Male	53.8%	35.6%	9.4%	1.2%
Telephone highway construction hot line:				
Both	0.5%	2.1%	4.9%	92.5%
Female	0.5%	1.7%	4.6%	93.2%
Male	0.4%	2.5%	5.2%	91.9%

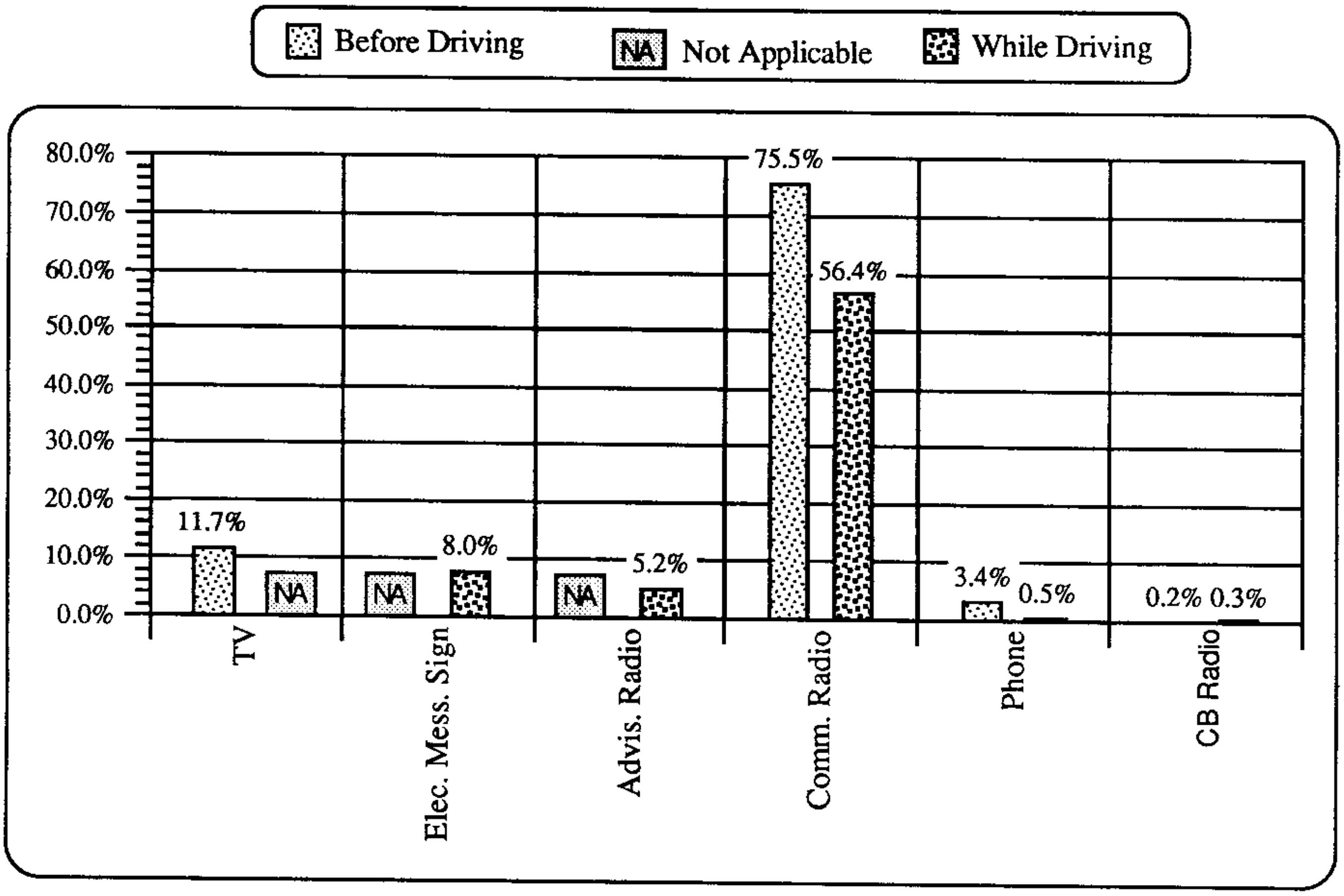

Figure 3. Preferred Sources for Receiving Traffic Information

When asked about their preferred source for obtaining traffic information, motorists strongly preferred commercial radio both before and while driving: 75.5% preferred to receive traffic information from commercial radio before driving; 56.4% preferred to receive traffic information from commercial radio while driving (see Figure 3 above). The lower percentage preferring radio while driving as compared to before driving is misleading, due to a high percentage of unusable responses. Actually, an equal percentage (@80%) of those who answered appropriately preferred commercial radio both during and before driving. (This was the only survey question where subjects' failure to respond appropriately had an impact on data analysis.)

When asked whether they would use various media to receive continual up-to-the-minute traffic information if specific media were available, most motorists (92.1%) stated that they would use a radio station dedicated to traffic information. Other studies have identified the preference for up-to-the-minute traffic information and specifically that provided by radio [7]. However, when asked if they would use a phone hot line, a cable TV station dedicated to traffic information, or a computer delivery system, only 33.7%, 25.4%, and 15.3%, respectively, answered yes. A California study [8] found that 53% of their sample desired a phone hot lone. A Mann-Whitney *U* test for gender differences revealed that females, more than males, stated that they would use either a phone hot line or a dedicated cable TV station. See Figure 4 for a graphic display of responses to the predicted use of the four hypothetical media.

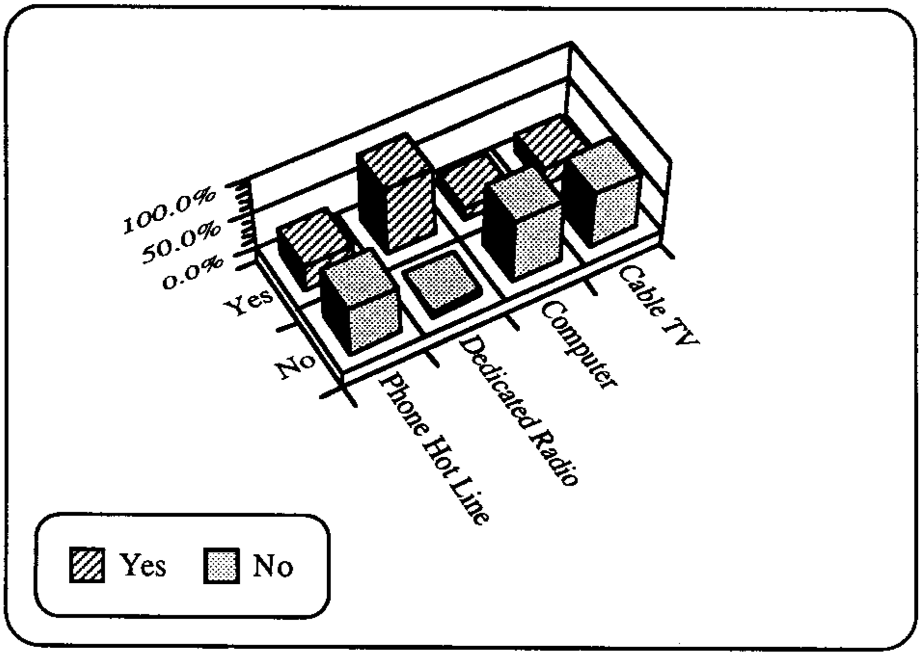

Figure 4. Preferred Media for Receiving Up-to-the-Minute Traffic Information

When asked which media they would like to see developed first, most motorists (86.2%) preferred to see the development of a radio station dedicated to traffic information, then a phone hot line (7.3%), a dedicated cable TV station (3.6%), and a computer delivery system (1.3%).

Demographic Information

The sample was evenly distributed across gender with 50.7% male respondents and 48.8% female respondents with 0.5% not responding. With regard to age of the respondents, the majority (61.1%) were under 41. A Mann-Whitney *U* test for gender differences on age revealed that females in the sample are younger than males, $p \leq .001$. (See Table 10.)

Table 10. Age of Motorists

Under 31	Both	24.5%	Female	30.7%	Male	18.5%
31-40	Both	36.6%	Female	38.7%	Male	34.5%
41-50	Both	4.6%	Female	21.5%	Male	28.5%
51-64	Both	12.3%	Female	8.6%	Male	16.0%
65 and over	Both	1.5%	Female	5.2%	Male	2.5%

The majority of motorists surveyed live in households with earnings above $50,000 per year. (See Table 11.) A Mann-Whitney *U* test revealed that females live in lower income households than males, $p \leq .001$. The age and income data together suggest that the people who responded to our survey were generally under 40 years old and lived in households with earnings between $50,000 and $59,999 per year.

Table 11. Annual Income For Motorists' Entire Household

Income	All	Fem.	Male	Income	All	Fem.	Male
No income	---	---	---	40,000-49,999	14.9%	14.7%	14.8%
Under $10,000	0.8%	0.9%	0.8%	50,000-59,999	16.1%	14.8%	17.3%
10,000-19,999	6.0%	8.6%	3.6%	60,000-74,999	14.7%	12.8%	16.7%
20,000-29,999	12.8%	17.8%	7.9%	75,000-100,000	11.0%	9.5%	12.4%
30,000-39.999	14.3%	15.2%	13.6%	Over 100,000	9.4%	5.8%	12.9%

As shown in Table 12 below, of the 1,698 motorists willing to participate in a follow-up interview, more males (44.7%) were willing than females (42.7%).

Table 12. Willingness to Take Part in a Follow-up Interview

Yes	Both = 43.7%	Female = 42.7%	Male = 44.7%
No	Both = 56.3%	Female = 57.3%	Male = 55.3%

Comment Summary

A total of 430 comments pertaining to traffic information were received and analyzed. An analysis of the comments was conducted to (1) describe the distribution of comments that related to different forms of traffic information and (2) identify issues that should be probed during the follow-up survey. Table 13 summarizes the distribution of comments across media.

Table 13 also depicts the distribution of positive and negative comments regarding present media and media that might be developed. Two groupings seem apparent from the distributions described in Table 13. Commercial radio, dedicated radio, and VMS were commented on most frequently: 77% of the total comments concerned these forms. All other media accounted for only 23% of the total comments. This distribution suggests that drivers are currently most concerned about traffic information that is available to them while they are in their cars. It further suggests that commuters are most interested in traffic information that has immediate reference to their driving decisions and that they may be unable to use available sources to plan alternate commuting routes. The follow-up survey thus included a set of questions probing these issues.

Table 13. Summary of Comments From Initial Survey

Media	Present		Future		TOTAL
	Positive	Negative	Positive	Negative	
Radio					
Commercial	47	105	43	0	195
Dedicated	1	27	32	6	66
Television					
Commercial	1	11	3	2	17
Dedicated	0	1	5	9	15
Telephone	0	4	18	12	34
VMS	2	46	21	1	70
CB	2	0	0	0	2
Computer	0	6	4	9	19
Ramp meters	0	8	4	0	12

Factor Analysis

The discussion presented so far has focused on the patterns observed for commuters as a whole. This section explores the principle components factor analysis of relevant variables from the initial survey; the principle components factor analysis was conducted to determine the communalities in commuters' responses rather than distinguishing characteristics.

Table 14. Rotated Factor Matrix*

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Frequency of traffic congestion affecting rte.	.66358				
Frequency of changing rte. to home	.65333				
Time of day affecting commuting rte.	.57434				
Frequency of changing rte. to work	.56501				
Frequency of traffic info. affecting rte. choice	.56003				
Delay length causing diversion to known alt rte.	-.54514				
Time pressure affecting commuting rte.	.52750				
On I-5, frequency that info. causes rte. diversion	.50430				
Delay length causing diversion to unknown alt rte.	-.49853				
Weather affecting commuting rte.	.43016				
Familiarity with alt. N/S rtes	.37234				
Distance home-work		.86859			
Driving time home-work		.82461			
Driving time work-home		.80572			
Distance on I-5 N bound		.78754			
Distance on I-5 S bound		.78327			
Willingness to participate in follow-up interview*					
Receive traffic info. via CB*					
Before driving, traffic info. influences time leaving			.65304		
Before driving, traffic info. influences rte. choice			.62076		
Receive traffic info. via commercial radio			.55388		
Never receive traffic info.			-.49574		
Helpfulness of commercial radio traffic info.			.49055		
Before driving, traffic info. influences mode			.48388		
Helpfulness of TV traffic info.			.40421		
Receive traffic info. via TV			.32681		
No./wk. driving I-5 to work*					
Helpfulness of VMS traffic info.				.71189	
Receive traffic info. via VMS				.70419	
Helpfulness of HAR traffic info.				.70333	
Receive traffic info. via HAR				.70249	
Helpfulness of phone traffic info.				.30879	
Receive info. by phone*					
Impt. placed on reducing commuting distance					.52465
Household income					-.46014
Age					-.39477
Gender					-.38710
Impt. placed on increasing commute enjoyment					.38167
Impt. placed on saving commute time					.37903
Impt. placed on increasing commute safety					.36408
Flexibility in time leaving work for home					-.33591
Flexibility in time leaving home for work					-.32868
Stress during commute to and from work*					
No. people in car when commuting*					

* Notes:

Factor 1 = Issues affecting route choice
Factor 2 = Distance/Time information
Factor 3 = Traffic information, particularly TV and radio
Factor 4 = Traffic information--specifically VMS, HAR, and phone
Factor 5 = Commute attributes and flexibility
* Lack of number in the factor solution indicates that these factors did not correspond with any of the five factors.

A five factor solution was imposed on the data, in order to allow for a parsimonious set of factors and in order to parallel as closely as possible the conceptual structure of the initial survey. This matrix of factor loadings was obtained using the VARIMAX rotation; the five factor solution accounted for 33.4% of the total variance in the correlation matrix. The five factors obtained (issues affecting route choice; distance/time information; traffic information, particularly TV and radio; traffic information, specifically VMS, HAR, and phone; and commute attributes and flexibility) had a good deal of conceptual overlap with the sections of the survey (attributes of the commute, route choices, use and preferences for traffic information, individual characteristics). Table 14 (above) presents the loadings of the selected variables on the five factors.

As should be evident from the discussion presented earlier, the initial survey provided detailed information on three of the factors: the distance/time factor, and the two traffic information factors. However, while the factor analysis does indicate that a great deal was learned about issues affecting route choice and commute attributes and flexibility, the picture is not complete. Thus, the factor analysis pointed to the need to probe these issues further in the in-depth interview

Remarks

While our most significant discoveries in terms of information system design were to come through the cluster analysis described below, the statistical analyses described thus far added considerable data to previous efforts which distinguished gender differences in driving behavior. Previous studies have indicated males are more flexible than females in terms of altering route while driving. This study replicated these findings, but also indicated that females are more flexible and attentive to available information in terms of pre-trip choices. Thus, females may put more effort into selecting their pre-trip route, making them less likely to abandon that choice. This sheds new light on previous data.

In terms of preference for traffic information, a large percentage of all groups preferred commercial radio as the medium. They also expressed a preference for development of a radio station dedicated to traffic information exclusively. Subsequent testing during the follow-up survey indicated, however, that increased familiarity with graphical mediums lead to a greater acceptance of and desire for motorist information delivered via that medium. It is crucial, therefore, to distinguish those results which represent an interesting slice of commuters at a particular time, from those generally applicable groupings and factors which can be used to tailor traffic information to impact the long-term behavior and decision-making of commuters.

CLUSTER ANALYSIS

This section discusses the methodology designed to separate commuters into groups of drivers with similar characteristics on certain variables. Of all the data generated during this project, the discovery through cluster analysis of distinct, stable motorist groupings with respect to driving behavior and information needs may be the single most significant finding for the purpose of tailoring specific driver information for Puget Sound area commuters.

The initial Motorist Information Survey generated a data set based upon 3,893 drivers and asked questions concerning drivers' commutes, route choices, types of traffic information received, and general household classification characteristics. Cluster analysis, a statistical method that uncovers an underlying structure in a data set by grouping the cases or subjects into similar groups according to statistical distance measures, was used for grouping drivers. The study concentrated on a particular group of variables that characterized the influence of traffic information on drivers with respect to time, route choice, and mode of transportation. The variables were elicited from questions C4 and C5 (a,b,c) from the survey (see Appendix I):

- C4. When you are on I-5, how often does traffic information cause you to divert to an alternate route?
- C5a. Before you drive, how often does traffic information influence the time you leave?
- C5b. Before you drive, how often does traffic information influence your means of transportation (e.g., car, bus)?
- C5c. Before you drive, how often does traffic information influence your route choice?

Cluster Analysis Methodology

The overall objective was to partition the entire group of subjects into mutually exclusive and exhaustive subgroups based upon similar responses to these questions. Statistical cluster analysis is a technique for grouping individuals into *previously unknown* groups. Therefore, it differs from other methods of statistical classification in that the number of groups is not usually known prior to the analysis. Many cluster programs allow the user to observe (from a single output) a "cluster tree" or dendrogram, from which the user can choose an appropriate number of clusters, using summary information on distances between and within clusters at each step. The more clusters there are, the more alike are the individuals in each cluster, but this process can be carried to the extreme where the number of clusters equals the number of individuals, with exactly one individual in each cluster. The other extreme is to classify all individuals into a single "grand cluster". A sensible grouping of the subjects will lie somewhere between the two extremes.

Because the number of cases (3,893) was large, it was not possible to run a single hierarchical cluster analysis including all possible groupings from 1 to 3,893. We therefore used a methodology that fixed the number of clusters for a given run: by observing the output for several runs, the results guided us to a choice for a number of clusters that had neither too few nor too many in each cluster and for which the cluster centers were well-separated. For this, we used the SPSS program QUICK CLUSTER (SPSS, 1986), set up for efficient clustering of a large number of cases. The algorithm has three basic steps. For k requested clusters, the algorithm selects k cases with well-separated, nonmissing values as initial centers. Each case is assigned to the nearest cluster center (measured by squared Euclidean distance) and the cluster center is then updated. As the process continues, the centers tend to migrate toward concentrations of observations. The final step of the algorithm reassigns each case to the nearest updated cluster centers.

Initial Cluster Separation

Initial Cluster Centers are displayed in Table 15 below. The description of the initial center for Group 1 is those commuters who are: rarely influenced by traffic information as to means of transportation or time leaving the house, but are frequently influenced by traffic information concerning route choice, and sometimes diverts to an alternate route from I-5. The Group 2 initial center is never influenced by, or claim to never receive, traffic information with respect to route, time, or means of transportation. The Group 3 initial center is those commuters who frequently divert from I-5 to an alternate route, are frequently influenced by traffic information with respect to time leaving, are not influenced with respect to mode of transport, and rarely let information influence initial route choice. The Group 4 initial center is those commuters who never divert to an alternate I-5 route, are often influenced by information with respect to time leaving, are sometimes influenced concerning transport mode, and are often influenced with respect to route choice.

Table 15. Initial Cluster Centers

Survey Question:		C4	C5a	C5b	C5c
Group:	1	2	0	1	3
	2	0	0	0	0
	3	3	3	0	1
	4	0	3	2	3

Response Code: 3=Frequently; 2=Sometimes; 1=Rarely; 0=Never

Final Cluster Centers

Final cluster centers are displayed in Table 16 below. The cluster analysis separated the 3,606 cases (those with no missing values on the clustering variables) into four major driver groups. The final center for Group 1 sometimes diverts to an alternate I-5 route, is sometimes influenced by traffic information concerning route choice, and is rarely influenced concerning time leaving or mode of transport. The final center for Group 2 rarely diverts to an alternate route from I-5,and is almost never influenced by traffic information regarding time leaving, means of transportation, or route choice. The final center for Group 3 sometimes diverts to an alternate I-5 route, and is sometimes influenced by traffic information concerning time leaving and route choice. The final center for Group 4 rarely diverts to an alternate I-5 route, is sometimes influenced by traffic information regarding time leaving and route choice, and rarely for mode of transport . The average score for transport however, is strikingly higher than for any of the other three groups, and in fact is higher than the average score for diverting to an alternate route.

Table 16. Final Cluster Centers

Survey Question:		C4	C5a	C5b	C5c
Group:	1	1.7	0.9	0.7	2.0
	2	1.1	0.6	0.4	0.6
	3	1.8	2.2	0.7	1.9
	4	1.3	2.3	1.5	2.2

Distances between the final cluster centers are shown in Table 17. The centers are well separated; the smallest distance is at least 1.025, slightly more than one scoring point apart. Not surprisingly, an ordinary one-way analysis of variance by group on each of the defining variables shows high descriptive F-scores (Table 18). These should not be assigned P-values like ordinary F-statistics for hypothesis testing, since the driver groups were statistically created to maximize between group separation and within group homogeneity. They can, however be used as another indication of cluster separation. Out of the 3,606 cases with no missing values, 744 (20.6%) were assigned to the first group, 844 (23.4%) to the second, 1,446 (40.1%) to the third, and 572 (15.9%) to the fourth group.

Table 17. Distances* Between Final Cluster Centers

		1	2	3	4
Group:	1	0.0			
	2	1.6	0.0		
	3	1.3	2.2	0.0	
	4	1.6	2.6	1.0	0.0

*Distance measure is Euclidean distance

Table 18. Analysis of Variance

Response	Between Cluster MS	df	Within Cluster MS	df	F=Between/Within
C4	112.2	3	.35	3602	323.3
C5a	669.5	3	.18	3602	3712.6
C5b	136.9	3	.30	3602	459.4
C5c	412.3	3	.32	3602	1274.7

Descriptions of the Driver Groups

From the results of the cluster analysis, we labeled the four driver groups in the following manner:

[1] *route changers*, willing to change routes both on I-5 and prior to leaving (20.6%),

[2] *non-changers*, unwilling to change departure time, route, or mode of transportation (23.4%),

[3] *route and time changers* (40.1%), and

[4] *pre-trip changers*, willing to make time, mode, or route changes before leaving home, but unwilling to change en route (15.9%).

In summary, *Route changers* (RC) often divert to an alternate route from I-5 and state that traffic information often influences their route choice, but not the time they leave nor their means of transportation. *Non- changers* [NC] rarely divert to alternate I-5 routes, and rarely or never change the time they leave, transportation mode, or route choice. *Route and time changers* (RTC) sometimes divert to an alternate I-5 route, often change the time they leave or pre-trip route choice, but not the mode of transportation. *Pre-trip changers* [PC] often alter the time they leave and pre-trip route choice, but rarely divert to alternate routes on I-5. These groups often arrange themselves in interesting ways, as will be seen below. They were further investigated to uncover similar characteristics with respect to other variables not used in the original cluster analysis. The driver groups proved to be stable both over other variables not used in the original cluster analysis and through subsequent in-person interviews of group members chosen at random.

Drivers' Commutes and Route Choices

The route changers (RC) appeared to have the shortest commute (southbound and northbound), as measured from where drivers entered and exited I-5. This result was confirmed by drivers' own estimates of distance and driving time. Around three-fourths of the drivers in each group have a single person in the car for the commute. Around 6% of the NC group has at least 3 people in the car (carpoolers); this may in part account for the general inflexibility of that group. The PC group has the highest percentage (25%) of couples in the car, which, if residents in the same household, may account for the higher likelihood to make commuting decisions before leaving the house.

With regard to *perceived stress* during one's commute, people who change the time they leave (RTC and PC groups, the "time changers") experience more stress than those who do not (RC and NC groups) (Table 19.). The "time changers" also care more in general about their commute with respect to saving time, reducing commute distance, increasing commute safety, and increasing commute enjoyment. (Tables 20-23). The concern and pre-trip flexibility of these departure time changers makes them prime candidates for home delivered motorist information.

Table 19. Stress Experienced During Commute

	A Lot	Some	Very Little
RC and NC	12.5%	55.8%	31.7%
RTC and PC	16.8%	60.7%	22.5%

Table 20. Importance in Saving Commute Time

	A Lot	Some	Very Little
RC, RTC, and PC	68.5%	28.0%	3.5%
NC	60.2%	33.5%	6.2%

Table 21. Importance on Reducing Commuting Distance

	A Lot	Some	Very Little
RC, RTC, and PC	18.4%	40.4%	41.2%
NC	14.0%	34.7%	51.2%

Table 22. Importance on Increasing Safety

	A Lot	Some	Very Little
RC and NC	49.2%	37.9%	13.0%
RTC and PC	57.8%	34.9%	7.3%

Table 23. Importance in Increasing Commute Enjoyment

	A Lot	Some	Very Little
RC and NC	31.7%	43.8%	24.5%
RTC and PC	41.4%	42.9%	15.7%

The RC group is highest (73%) in terms of *familiarity* with north-south routes as alternatives to I-5 (the other three group averages around 60%) (Table 24.). The RC and RTC groups had the highest responses (7%) in terms of frequently modifying or changing the route from home to work (Table 25.). As for modifying the route from work to home, as expected, the NC group scores the lowest on "frequently" and the highest on "rarely."

Table 24. Familiarity with Alternate North-South Routes

	Very	Somewhat	Not at All
RC	2.7%	24.3%	73.1%
NC, RTC, and PC	5.3%	35.0%	59.7%

Table 25. Frequency of Route Change

Home to Work/ Work to Home	Frequently	Sometimes	Rarely
RC	7.5%/17.4%	38.0%/52.3%	54.5%/30.3%
NC	3.4%/10.8%	20.1%/31.6%	76.5%/57.6%
RTC and PC	6.6%/14.9%	32.7%/45.1%	60.7%/40.0%

Effects of Various Factors on Route Choice

The RC group sometimes or frequently makes changes according to the following factors: actual congestion (89%) (Table 26.), traffic reports/messages (86%) (Table 27.), time of day (65%) (Table 28.). That group responds less so to time pressures (44%) (Table 29.) or weather conditions (35%) (Table 30.). The NC group consistently responded highest on "Rarely" and lowest on "Frequently" for all factors. The RTC and PC groups, the ones who will change departure times, responded similarly to each other. They will sometimes or frequently make route changes according to: traffic reports (84%), traffic congestion (81%), time of day (66%), and, unlike the RC group, time pressures (57%). Thus the groups which are most likely to alter pre-trip travel decisions are also most influenced by traffic reports and time pressures.

Table 26. Frequency of Route Change due to Traffic Congestion

	Frequently	Sometimes	Rarely
RC	36.0%	52.5%	11.5%
NC	18.1%	45.0%	36.9%
RTC and PC	29.5%	51.8%	18.7%

Table 27. Frequency of Route Change due to Traffic Reports and Messages

	Frequently	Sometimes	Rarely
RC, RTC, and PC	33.5%	51.0%	15.4%
NC	9.2%	39.7%	51.1%

Table 28. Frequency of Route Change due to Time of Day

	Frequently	Sometimes	Rarely
RC, RTC, and PC	26.4%	39.5%	34.0%
NC	14.3%	31.9%	53.8%

Table 29. Frequency of Route Change due to Time Pressure

	Frequently	Sometimes	Rarely
RC	9.7%	34.2%	56.1%
NC	6.0%	25.7%	68.3%
RTC and PC	16.2%	41.7%	43.1%

Table 30. Frequency of Route Change due to Weather Conditions

	Frequently	Sometimes	Rarely
RC	6.5%	28.4%	65.1%
NC	3.3%	17.6%	79.1%
RTC	9.1%	34.1%	56.8%
PC	13.2%	33.8%	53.0%

Length of Delay Before Diverting to Known or Unknown Alternate Routes

The NC and PC groups had the highest mean time of delay before diverting to a known alternate route (around 17.5 minutes), the RC group the lowest (13.5 minutes) (See Table 31.). The NC and PC groups had the highest means (27.4 minutes) while the RC group the lowest (22.1 minutes) with respect to changing to an unknown alternate route. This is consistent with the route-changing nature of drivers in the RC Group . Similarly, the NC Group constitutes the Non-Changers, while the PC group makes decisions before leaving the residence; both groups are less likely to make changes en route.

Table 31. Length of Freeway Delay in Minutes before Diverting to:

	Known Alternate Route		Unknown Alternate Route	
	Mean	Std. Deviation	Mean	Std. Deviation
RC	13.53	8.26	22.13	13.25
RTC	16.53	11.01	25.48	15.41
NC	17.85	12.18	27.36	17.42
PC	17.08	10.44	27.41	15.04

Media from which Information Is Received

The RC, RTC, and PC groups tended to exhibit similar characteristics with respect to many of these variables. The NC group usually had a higher percentage responding that they had never received traffic information from a particular medium. For this discussion, the RC, RTC, and PC groups taken together are referred to as "changers" to contrast with Group 2, the non-changers. The majority of the changers never receive traffic information via television (65%-70%) with an even higher percentage of the non-changers (83%) never receiving information from television. Around one-half of all groups, though more non-changers, claimed never to have received information from electronic message signs over I-5 (changers, 43%-45%; non-changers, 54%). One-half of the changers had never received information from advisory radio indicated by flashing lights on highway signs (52%-54%); 65% of the non-changers had never received such information. In general, groups who were less likely to modify a given driver behavior were also less likely to receive information relevant to that behavior. This is an important conclusion for the design of motorist information systems (see "INTERPRETATION, APPRAISAL, APPLICATION" below).

Finally, 78%-85% of all the groups preferred commercial radio as the medium for traffic information both prior to leaving and while driving. Television was the second choice prior to leaving home (12%-14%) and VMS was the second choice while driving (10%-12%).

Help from Traffic Information Delivered by Various Sources

While one-half to three-fourths of the groups never used TV to receive traffic information, there were clear differences between groups as to how helpful they felt televised traffic information was. Twenty-eight % of the PC group found TV somewhat or very helpful as compared to 23% of RTC, 14% of RC, and only 7% of the NC group. This ordering of groups (PC, RTC, RC, NC) finding various media somewhat or very helpful followed for almost all cases with VMS ranging between 40% (PC) and 28% (NC), HAR ranging between 39% (PC) and 19% (NC), and commercial radio ranging between 95% (PC) and 75% (NC). The PC, RTC, RC, NC ordering is a general reflection of driver receptivity to motorist information, and is another useful insight for the design of motorist information systems (see "INTERPRETATION, APPRAISAL, APPLICATION below").

Point of Preference for Receiving Traffic Information and Choosing Commuting Route

The PC group has the highest response (77%) preferring to receive information before driving. Pre-trip changers are also most likely of all the groups (47%) to choose their commuting route at home or work, and the least likely (11%) to make a change en route (Table 32.). The RTC group has the second highest percentage (64%) preferring to receive information before driving; a lower percentage (35%) actually choose the route at home or at work, while half choose the route on city streets or near entrance ramps. The majority of the RC group are most likely to choose their commuting route on city streets or near entrance ramps. However, almost half prefer to receive traffic information at home or at work. About 10% of the NC group prefer to receive traffic information on I-5 as opposed to only 5%-3% for the other driver groups, even though they do not seem to make use of it.

Table 32. Where Commuting Route is Chosen

	Home/Work	City Streets	Near Entrance Ramps	On I-5
RC	22.4%	30.6%	30.6%	16.3%
NC and RTC	35.0%	22.2%	25.7%	17.1%
PC	47.0%	19.8%	22.1%	11.2%

Use of Proposed Up-to-the-Minute Traffic Information

A dedicated radio station was the most preferred proposed medium for the delivery of up-to-the-minute traffic information. Even the NC group, which tends not to actively seek out traffic information, had a high percentage (84%) responding that they would make use of traffic information on such a medium. The other three groups, which do actively seek out information, responded even higher (93-96%) on dedicated radio. Other sources of traffic information received much lower responses. For a proposed phone hot line, the three "changer" groups ranged from 30%-42% responding "Yes," the NC group was low with 23%. Traffic information delivered by computer elicited a large negative response (81%-85% "No"). For a proposed cable TV station dedicated to traffic information, the PC and RTC groups averaged 32% "Yes", followed by the RC group (20%) and the NC group (16%). It makes sense that the two groups which make pre-trip changes would be most interested in TV delivery of motorist information.

Would Like to See the Following Services Developed First:

All four groups are 84%-90% for developing a dedicated radio station first. Around 90% of each group have radio available to them at home/car or home/office/car. Although 80% of each group have available phone facilities at home and office, only 6%-8% wanted to see telephone hot line traffic information services developed first. Similarly, although 83%-85% of all groups have TV at home (60%-66% have a TV cable hook-up), less than 5% wanted to see a dedicated traffic station developed first. Although 57%-64% of all groups have computer facilities available at home, office, or both, only 1%-2% wanted to see computer-based traffic information services developed first.

Demographics for the Four Driver Groups

Gender of respondents: Males predominated in the RC and NC groups; females predominated in the RTC and PC groups. In terms of percentage of male respondents, the four driver groups were 57% (RC), 61% (NC), 46% (RTC), and 42% (PC).

Age of respondents: Across groups, very few (1% or less) were in the 65 and over age bracket. Around 10%-14% were 51-64 years of age; around 25% were 41-50 years of age; 35%-42% were 31-40 years of age; 21%-29% were under 31. A Kruskal-Wallis analysis of variance by ranks rejected the null hypothesis of equality of mean age (rank) in the four groups, with the RC and NC groups showing the highest mean age rank and the RTC and PC groups having lower mean age ranks.

Income: The RC and NC groups report the highest income; the RTC and PC groups the lowest. The PC group, which is the only one to change mode of transportation, and which has the highest percentage of female respondents, also displays the lowest income.

Pre-trip flexibility seems to correlate with younger, female, and lower income commuters.

Remarks

Investigation of characteristics other than the initial clustering variables confirmed the results for the four driver groups. The Route Changers have the shortest commutes, are most familiar with alternate north-south routes to I-5, will indeed modify their routes, and will wait the shortest times before switching to known or unknown routes. The Non-Changers are generally unwilling to change time, route, or mode. The Route-and-Time Changers are willing to change both route and time and experience more stress as a result (or vice versa). The Pre-trip Changers have the highest percentage willing to change modes of transportation, will make more changes before leaving the house and fewer en route, and also experience more stress than the RC or NC groups.

In terms of preference for traffic information, a large percentage of all groups preferred commercial radio as the medium. They also expressed a preference for development of a radio station dedicated to traffic information exclusively. Subsequent testing during the follow-up interviews indicated, however, that increased familiarity with graphical media lead to a greater acceptance of and desire for motorist information delivered via that medium. It is crucial, therefore, to distinguish those results representing an interesting slice of commuters at a particular time from those generally applicable factors which can be used to tailor traffic information to affect the behavior and decision-making processes of commuters.

RESULTS FROM THE IN-DEPTH, FOLLOW-UP SURVEY

The data obtained from the in-depth interview were analyzed in a manner similar to the data from the initial survey. The responses were examined for patterns across the entire sample and were further examined for patterns across clusters, genders, and mileage travelled. Finally, a principle components factor analysis was conducted to reveal communalities of responses.

Patterns Across the Entire Sample

Behavior and Decisions Prior to Departure

Commuters report that they have an average of approximately 70 minutes ($M = 71.969$, $SD = 32.391$) between the time that they wake up and the time they depart for work. During that period they must accomplish at least one significant task ($M = 1.063$, $SD = 1.296$) other than preparing themselves to leave, such as preparing breakfast for other members of the household. The majority of commuters report that they perceive this period to be relatively calm (60.42% rated the period as a 1 or 2 on a five-point scale of "hecticness") and relatively stress-free (66.67% rated the period as a 1 or 2 on a five point scale of stress).

The majority of commuters (72.92%) receive traffic information of some kind during the period prior to their departure and report that they first receive traffic information quite soon after awakening. Half of the commuters report that they first receive traffic information pertaining to their primary route almost immediately after awakening; an additional 10% of commuters (for a total of 61.43%) report that they receive their first traffic information more than one hour prior to departure. Commuters report they receive traffic information at least three times ($M = 3.059$, $SD = 2.143$) between awakening and departing.

While commuters (on the whole) report that they are aware of traffic information, they report that this information has little impact on their decisions prior to departure. The majority of commuters report that they rarely decide to use an alternate route (65.71%), that they rarely decide to use an alternate mode (90.00%), and that they rarely decide to change their time of departure (64.29%) based on information they receive prior to departure. In an average month, commuters report that they decide to change their route twice ($M = 2.333$, $SD = 2.666$) prior to departure. (As indicated below, conditions warrant more frequent adjustment than this, since commuters are late due to traffic conditions around four times a month.)

On the whole it appears that commuters are receptive to traffic information delivered prior to departure. They report that the period prior to departure is not a very stressful period and that they have a relatively small number of tasks to accomplish. The low rate of modification to route, mode, and time of departure may indicate that, while commuters receive traffic information, they do not find the information to be credible. This inference is supported by the high rate of negative comments about existing information media received from commuters on the initial survey. The low rate of route modification may also be due to the temporal delay between receipt of the information and decision, the majority of commuters having reported that they receive their first traffic information more than one hour prior to departure.

For purposes of designing an information system, these results reinforce that demonstrating system credibility is an extremely significant issue. In addition, commuters seem to have the time to use an interactive information system that would demand some active participation, i.e., a computer-based graphical system.

Behavior and Decisions En Route

Commuters indicated a high degree of knowledge regarding their primary commuting route and their first and second alternate routes. Indications of route knowledge were obtained from counts of the number of landmarks and street names used when commuters described their commuting routes. Results support the intuitive prediction that commuters have a more detailed knowledge of their primary route than of either their first or second alternate routes. Commuters, when asked to trace their commuting routes, used five times as many street names as they did landmarks in describing their routes. Table 33 summarizes the means and standard deviations for number of street names and landmarks used by commuters to describe their primary route and their first and second alternate routes.

<u>Table 33. Number of Street Names and Landmarks Used in Descriptions of Commuting Routes</u>

		Primary Route	First Alternate	Second Alternate
Street names	mean	8.45	5.02	4.26
	sd	*6.23*	*3.70*	*4.01*
Landmarks	mean	1.67	1.03	0.79
	sd	*1.89*	*1.48*	*0.90*

The overwhelming majority of commuters (97.92%) report that they use I-5 as their primary route into the city. Of commuters who both knew of and used an alternate route, half reported that both their first and second alternate routes avoided I-5 (52.94% for the first alternate route, 50.90% for the second alternate route). The majority of commuters (95.83%) reported that they knew of an alternate to the route they normally use, one they would use if a large portion of their normal route were inaccessible for some reason. However, a smaller majority (75.00%) reported that they actually use one of those alternate routes. Commuters on average reported knowing between two and three routes that would serve as alternate routes (M = 2.880, SD = 1.568).

On the whole, commuters reported that they had few tasks (M = 0.611, SD = 0.982) to complete (such as dropping off a family member) on their normal drive into the city. The majority of commuters (58.95%) reported that they experience low to moderate levels of stress on their primary route. If they decided to use an alternate route, 80.88% of commuters reported that the level of stress experienced changed and 77.78% reported that the level of stress experienced increased. Thus use of an alternate route represents an increase, rather than a decrease, in stress.

While commuters reported that their choice of route was relatively stable, they also reported that they make between one and two adjustments to their normal route each day (M = 1.552, SD = 1.897). The adjustments in route primarily occurred in response to observed traffic congestion and reports of traffic congestion received in the car (i.e., traffic radio reports). At the first decision point, observed traffic congestion was cited by 39.47% of commuters as the reason for making a route adjustment while traffic information was cited by 35.71% of commuters. At the second decision point, the percentage of commuters who responded to observed traffic conditions as opposed to traffic reports was even greater: 54.76% cited observed traffic conditions as the reason for making their second route adjustment while 23.81% cited traffic information received in their cars.

If they committed to using an alternate route, commuters reported that they made fewer adjustments to their alternate routes than they did to their primary route (for the first alternate route, M = 0.647, SD = 1.182; for the second alternate route, M = 0.474, SD = 0.928). The decision to use an alternate route was based first on traffic information received in the car (33.28% for the first alternate route, 35.09% for the second alternate route) and second on observed traffic conditions (23.53% for the first alternate route and 21.05% for the second alternate route). Interestingly, approximately one-quarter of the commuters who used alternate routes reported that they sought out information about the use of an alternate route while at home, more than 30 minutes before departing (26.87% for the first alternate route, 24.56% for the second alternate route).

Commuters reported that they received little feedback regarding their choice to use an alternate route and what feedback they did receive was relatively delayed. Nearly one-third of the commuters indicated that they had no way of telling if their choice to use an alternate route was correct or incorrect (27.94% for the first alternate route, 31.58% for the second alternate route). The majority of commuters indicated that if they did receive any kind of information confirming or refuting their choice to use an alternate route, they received it more than five minutes after making the choice (69.57% for the first alternate route, 48.72% for the second alternate route). Only a small percentage of commuters (2.94%) indicated that they received this information from radio traffic reports.

The patterns observed for all commuters indicate that commuters have a high degree of knowledge of their primary and alternate routes, that a majority use alternate routes, and that nearly half of the alternate routes make use of some portion of I-5 (the primary route used by commuters into downtown). It appears that commuters are not overly burdened with additional tasks other than simply commuting to the workplace and that approximately one-third of all commuters experience high levels of stress, with the perceived level of stress increasing if an alternate route is used. Commuters appear to make a small number of adjustments to their primary route, based mainly on their observations of traffic conditions. However, commuters appear to decide to use an alternate route based on traffic reports received either at home or in the car. Finally, commuters receive little feedback regarding their choice to use an alternate route and, when received, this feedback is usually delayed.

The implications for design of an information system for commuters en route are somewhat similar to those for an information system designed for commuters before departure. While commuters do rely on traffic reports, they require that information be more current, more specific, and verified as reliable through feedback. Increasing currency and specificity might well increase the probability of choosing an alternate route (as opposed to merely making minor adjustments to the primary route). Incorporating feedback mechanism into on-road systems for delivering information should increase their effectiveness in encouraging alternate route selection.

Behavior Post-Commute

Commuters reported that they were late for work due to traffic conditions about four times in an average month ($M = 4.097$, $SD = 4.099$). Commuters were asked to rate their flexibility in arrival times: their responses were distributed evenly across a five point scale. The majority of commuters (82.29%) indicated that the penalties for arriving late for work were relatively minor.

Summary

This description of the behavior and decisions of commuters prior to departure, en route, and post-commute provides a number of implications for the design of information systems. It indicates that (1) commuters are likely to benefit from two different types of information systems, one used pre-departure and one used en route; (2) these two systems should be integrated to provide feedback and confirmation of reliability (post-commute delivery might be effective as well) and (3) the information transmitted needs to be more current and specific in order to be used and acted upon. These implications, however, are somewhat limited in scope and do not address the need to change commuter behavior under specific conditions. The analyses reported in the following sections (patterns across commuter group, gender, and mileage groups and the patterns observed in the factor analysis) give a much more detailed view of commuter responses and underscore the idea that commuters are not a homogeneous population in terms of traffic information needs.

Patterns Across Commuter Group

Group membership for each commuter participating in the follow-up survey was determined based on the cluster analysis performed on data from the initial survey. The four clusters, as described above, were defined as (1) RC, or route changers; (2) NC, or non-changers; (3) RTC, or time and route changers; and (4) PC, pre-trip changers. The responses of the commuters participating in the follow-up survey were examined to determine if there were any significant differences in behavior and decisions attributable to cluster membership. Continuous variables were analyzed using analyses of variance (ANOVAs) and categorical variables were analyzed using Kruskal-Wallis non-parametric ANOVAs. This section reports only those analyses that produced results significant at $p \leq 0.05$; results with probability values $>.05$ but ≤ 0.10 are reported as trends.

The highest flexibility in departure time was reported by members of the RTC cluster. The RTC cluster was followed (in terms of decreasing flexibility) by the RC, PC, and NC clusters. Members of the RTC cluster were also most likely to change their route based on traffic information they received prior to departure. The RTC cluster was followed (in terms of decreasing probability of changing route based on information received prior to departure) by the RC, PC, and NC clusters, rather similar to the previous departure flexibility question. Members of the RTC and PC clusters indicated that they selected an alternate route more frequently in an average month than the members of the NC cluster (no significant difference was noted for the RC cluster). Finally, the members of the NC cluster indicated more frequently than members of the other clusters that they did not know of any alternate routes to their primary routes.

There was a trend for members of the RC cluster to more actively seek out information regarding traffic conditions on their primary route. The RC cluster was followed by the RTC, PC, and NC clusters. However, members of the PC cluster seek out information regarding traffic conditions more frequently prior to departure than members of the NC cluster (no significant differences were found between the RC and RTC clusters).

Members of the NC cluster appeared to have lower levels of knowledge regarding their primary and first alternate routes than members of the other clusters. There was a trend for members of the NC cluster to use more landmarks (as opposed to street names) in their descriptions of their primary routes. The lower level of knowledge regarding the route became more apparent on the first alternate route. Members of the NC cluster did use significantly more landmarks (as opposed to street names) in their descriptions of their first alternate routes.

While members of the NC cluster appear to have lower levels of knowledge of their primary and first alternate routes, they also appear to experience lower levels of stress when using their primary route. The NC cluster was followed (in terms of increasing stress on the primary route) by the RC, RTC, and PC clusters. However, when using an alternate route, members of the RC cluster reported that the level of stress experienced was likely to decrease, while members of the NC, RTC, and PC clusters reported that the level of stress was less likely to increase.

Findings like these can help fill out our picture of the commuter groups discovered in the initial survey and tell us more about targeting information for these groups. For example, the first survey data indicated that members of the NC cluster found traffic information received at home less preferable and had less positive reactions to messages and media. These results indicate that members of the NC cluster have lower levels of knowledge regarding their primary and alternate commuting routes. Operationally, this means that members of this cluster were more likely to use landmarks rather than street names in describing their commuting routes. Since the majority of the available traffic information sources rely on the use of street names in the description of routes, members of this cluster (having a lower knowledge of the street names on their commuting routes) would be less likely to find the information usable or to act on that information. Thus, an information system targeting members of the NC cluster might need to provide more graphic information, such as video displays of traffic conditions. The information system might also need to provide greater levels of information regarding alternate routes (perhaps even offering an option that would increase commuters' familiarity with the available routes, in the fashion of a tutorial). Finally, it may be that the educational requirements for motorist information that would impact members of the NC group make such information impractical (See "INTERPRETATION, APPRAISAL, APPLICATION" below).

Patterns Across Gender

Only a small number of gender differences were uncovered in the analyses of the responses to the in-depth interview. Females indicated that they tended to have less flexibility in the time of departure (x^2 (4) = 8.700, $p \leq 0.069$) and that they had less flexibility in the time of arrival ($x^2(5) = 12.599, p \leq 0.014$). Females also rated the period prior to departure as more hectic than males ($x^2(4) = 9.187, p \leq 0.057$). Finally, females were more likely than males to be living alone ($x^2(1) = 6.099, p \leq 0.014$).

These findings imply that even more than males, females with greater time demands placed on them need an information system that provides time estimates of traffic delays and commuting routes. In a more general sense, these finding indicate that commuters differ even by gender with regards to aspects of their commute and their use of and response to traffic information, thus supporting further the notion that commuters can not be treated as a unitary whole.

Patterns Based on Commute Distance

"Mileage groups" were determined based on data provided by commuters on the initial survey. Mileage groups were defined based on the number of miles commuters travelled on south-bound I-5 and relative to major on-ramps to south-bound I-5. The mileage groups are summarized in Table 34. Refer to Appendix V for a map of Seattle area freeways with major on-ramps.

Table 34. Mileage Group Definitions

	Miles on Southbound I-5	Major On-Ramp
Mileage group 1	≤ 2.0	SR 520
Mileage group 2	> 2.0, ≤ 4.0	522 (Lake City Way)
Mileage group 3	> 4.0, ≤ 9.0	110th (Northgate)
Mileage group 4	> 9.0, ≤ 16.0	Alderwood
Mileage group 5	> 16.0, ≤ 26.0	Everett
Mileage group 6	> 26.0	North Snohomish County

Only a small set of trends were found between members of the mileage groups. Kruskal-Wallis test statistics and probability values for the comparisons are presented in Table 35.

Table 35. Significant Findings for Mileage Groups

Variable	Kruskal-Wallis Statistic	p
Seek information on primary route	8.023	0.091
First alternate route returns to primary	7.784	0.100
Confirm choice of first alternate route	8.994	0.061

Commuters entering southbound I-5 from the SR-520 on-ramp (and south) and commuters entering between 110th (Northgate) and Alderwood (Groups 1, 3, 4) tended to most actively seek out information regarding conditions on their primary route prior to departure. Commuters entering southbound I-5 between Alderwood and Everett (Group 5) tended to be least likely to actively seek out traffic information prior to departure.

Commuters entering southbound I-5 from the SR-520 on-ramp (and south) and commuters entering between 110th (Northgate) and Alderwood reported that their first alternate route tended to return at some point to the path of their primary route. Commuters entering southbound I-5 at Northgate reported that their first alternate route tended not to return to the path of their primary route.

Commuters entering southbound I-5 from between the SR-520 on-ramp and the 522 (Lake City Way) on-ramp reported that they tended to most likely use their own observations of traffic congestion and information from traffic reports to confirm or refute their decision to use their first alternate route. Commuters entering southbound I-5 from between Alderwood and Everett reported that they tended to confirm their decision to use their first alternate route in the absence of traffic information (i.e., they were convinced the decision was correct or incorrect without relying on observations of traffic congestion or traffic reports).

With regards to the design of traffic information systems, these findings point towards the need for temporal and geographic specificity and differing levels of detail of information. Commuters in the areas that are most heavily covered by commercial traffic reports (the SR-520 bridge, north Seattle, and Lynnwood) tended to rely on traffic reports both prior to departure and in confirming or refuting their decision to use their first alternate route. Also, commuters who would be most familiar with possible alternate routes into downtown (those commuters living in north Seattle) tended to report that their first alternate route did not return to the path of their primary route. This may indicate the need for information systems to provide more current and detailed information designed to both influence decisions to use alternate route and to increase commuters' awareness of viable alternate routes.

Results of the Factor Analysis of Responses to the In-Depth Interview

The discussions presented so far have presented patterns that could be attributed to characteristics of commuters (such as gender) and their commuting tasks (such as miles travelled). As was done for the initial survey, a principle components factor analysis was performed on the responses to the in-depth interview to determine communalities of responses rather than distinguishing member characteristics. In essence, cluster membership, gender, and distance travelled allowed commuters to be reliably distinguished. The principle components analysis allowed the responses of commuters to be analyzed for common features.

The five factor solution obtained (distance/time, personal characteristics, knowledge of primary route, knowledge of alternates, and response to stress) had an interesting degree of conceptual overlap with the five factors obtained for the initial survey (issues affecting route choice; distance/time information; traffic information--TV and radio; traffic information--see above). Table 36 presents the loadings of the selected variables on the five factors. The matrix of factor loadings was obtained using the VARIMAX rotation; the five factor solution accounted for 71.816% of the total variance in the correlation matrix.

Table 36. Factor Loadings for Five Factor Solution, Commuter Responses to In-Depth Interview

Variable	Distance/ Time	Personal Chars.	Primary Knowledge	Alternate Knowledge	Stress Resp.
Mileage	0.831				
Tasks, pre-depart	-0.773				
Time, pre-depart	-0.662				
Penalties, late arr	-0.543				
Age of youngest child		0.909			
Age of commuter		0.888			
Flexibility, arrival		0.720			
Times seek info, pre-depart		0.628			
Flexibility, departure		0.590			
Gender of commuter		0.498			
Street names in desc.			0.863		
Landmarks in desc.			0.817		
Actively seek info, pre-depart			-0.578		
Stress, pre-depart				-0.859	
Seeks info, pre-depart				0.771	
Tasks, primary route				-0.647	
Change in stress, alt. routes				0.625	
Number of alt routes known				0.617	
Stress, primary route					0.822
Modifications, primary route					0.759

Just as knowledge of the communalities of the responses of commuters participating in the first survey allowed refinement of the in-depth survey, knowledge of the communalities of responses in the in-depth interview allows an even finer set of conclusions to be reached regarding traffic information systems. Further, these factors reinforce the importance of not considering commuters as a homogeneous whole when designing motorist information systems.

Designers of effective information systems that will impact commuter behavior thus need to consider the distance travelled by commuters and the time available to commuters, personal characteristics of the commuters, knowledge of primary and alternate routes, and commuters' levels of stress. The distance/time factor indicates that, with increasing commuting distance, commuters have less time available prior to departure, they accomplish fewer significant tasks prior to departure, and they feel the penalties they might pay for being late are minor. The personal characteristics factor indicates positive correlations between the age, gender, age of the commuter's youngest child, flexibility of arrival and departure, and times the commuter seeks information prior to departure. The primary route knowledge factor shows the relationship between the detailed knowledge of street names and landmarks and the time at which commuters first seek out information regarding traffic conditions on their commute. The alternate route knowledge factor demonstrates the intercorrelations of number of alternate routes known, stress when using an alternate route, stress experienced prior to departure, how actively commuters seek out their first traffic information, and the number of tasks performed on the commute. Finally, the stress response factor shows the relationship between the number of modifications made to the primary route and the amount of stress experienced on the average commute.

Analysis of Responses to VMS Message Manipulations

This section discusses the analyses of the data from the tests of the variations on the variable message sign (VMS) messages. As discussed earlier, reaction time measures, and measures of accurate perception and probability of changing route in response to the messages were taken. Results were analyzed using repeated-measures analyses of variance (ANOVA). Values of the *F*-statistic and probability values across several variables are displayed in Table 37.

The only significant difference in reaction time was observed for the comparison of specific versus generic tasks. When commuters were presented with a specific task (i.e., a specific recommendation for alternate route), they responded faster (M = 2.335 sec) than when presented with a generic task (M = 2.458 sec). Commuters were also more likely to correctly interpret the message when presented with a specific task rather than a generic task; further, they were more likely to correctly interpret the message when the reason was presented before the task.

Table 37. Significant Results of VMS Repeated Measures Analyses

Variable	F	p
Reaction time, generic vs specific task	5.923 (1, 90)	0.017
Correct response, generic vs. specific task,	9.141 (1, 83)	0.003
task first vs. reason first	16.719 (1, 83)	0.001
Probability of route change,		
generic vs. specific task,	141.142 (1, 89)	0.001
task first vs. reason first	66.726 (1, 89)	0.001
Probability of route change, generic vs. specific reason, task present vs. task absent	22.173 (1, 94)	0.001

Interestingly, a pattern in opposition to the pattern just discussed was observed for the probability of commuters changing route in response to the message. Commuters indicated that they would be more likely to change their route when the message presented a generic (rather than specific) task and when the task (rather than the reason) was presented first. Finally, commuters indicated that they would be most likely to change their route in response to a message if the message presented a generic reason and the task were absent.

It appears that task information was of secondary importance to commuters. Further, it appears that commuters preferred generic reasons. This may indicate that commuters wish only to know that a traffic problem exists and that they wish to tailor their response to their specific commuting goals. These findings also may be medium dependent, in that the observed pattern of commuter responses may not be observed if, for example, the messages were delivered by radio.

Results and Discussion of the Graphics Questionnaire

The next section discusses the results of the analyses performed on data from the graphics portion of the follow-up survey. The results for each question are presented in the same order in which the questions were asked on the graphics questionnaire. (Refer to Appendix VI: Screens for the Graphics Questionnaire.)

Delay Time

During the test scenario, subjects responded that Screen 5 would be the most likely to cause them to delay departing home. Screen 5 described the same traffic conditions as the other screens (with the exception of the control screen, Screen 2). The mean time delay for Screen 5 was 14.5 minutes.

A weighted-mean was developed for each screen, consisting of the number of subjects times the mean delay. This was done because a high mean with few subjects responding is a false indication of magnitude of screen influence when compared to a slightly lower mean with many subjects responding. Using this measure, Screen 5 had the highest weighted-mean of 4.26. Screens 3, 1, 4 and 2 had weighted-means of 3.58, 2.64, 1.46 and 0.22 respectively. The Route and Time Changers consistently delayed more often and tended to delay longer then all other clusters, except in their responses to Screen 4. See Table 38 for weighted-mean values.

Table 38. Screen Causing the Most Time Delay

Screen	Time Del[1]	n[2]	n[3]	Weighted-Factor[4]	Weighted-Mean[5]
1	11.2	5	16	2.25	2.64
2	15.0	1	3.00	0.147	0.220
3	11.1	22	2.23	0.323	3.585
4	11.1	9	2.22	0.132	1.465
5	14.5	20	2.90	0.294	4.263

NOTE: Screen 2 was a control, showing very light traffic conditions while all other Screens showed the same traffic situation.

1 Mean time delay caused by the screen (in minutes).
2 Number of responses.
3 Mean response with 1= 5min, 2= 10min, 3= 15min, 4= >15min.
4 Number of responses divided by the total number of responses (d= 68).
5 Weight factor times mean response.

Use of Alternate Route

Approximately 72% of the subjects chose to take an alternate route after viewing the information on Screen 5. There was no significant difference across clusters in response to this screen, except for the Non-Changers, who diverted to another route the least often (55% of the time). The Pre-trip Changers, Route Changers and Route and Time Changers diverted to another route 86%, 77% and 67% of the time, respectively. But the difference in frequency between each of the changing clusters is only one. The number of positive respondents was 19, 20, and 18 respectively for Pre-trip Changers, Route Changers, and Route and Time Changers. Screen 3 caused almost the same amount of route alteration, approximately 70%. The trend across clusters was exactly the same as for Screen 5.

Change of Mode

The results for change of travel mode are similar to those for delay time and use of alternate route. Subjects shown Screen 5 chose to change mode most often, followed by Screen 3. Mode change was much less frequent than time or route change; only 10% of respondents said that they would change mode of travel. This suggests that although TV screens may provide bus and carpool information, it will be acted upon by only a minority of viewers.

Single Screen Choice

Over half the subjects (55.7%) chose Screen 5 as the screen they found most helpful in planning their commute. The next most helpful screen was Screen 1 with approximately 14%-27% selecting this screen. The third and fourth most desired screen varied across clusters.

The subjects were also asked why they would prefer one screen above all others. Screen 5 was most preferred by commuters because of the amount of information on the screen, and the time estimates provided. The second most preferred screen was Screen 1, with 21.6% of subjects choosing this screen. The chief reason for selecting Screen 1 was the text message it contained. The clusters do not appear to differ significantly in their reasons for selecting a screen.

Subjects responded most favorably to information that parallels the criteria they now use to evaluate traffic conditions. This type of information included time estimates and text messages which describe situations and provide options (similar to messages provided by radio and TV).

Value of Forms of Information

The subjects were asked to rank order all five forms of information according to how helpful they were in selecting a driving option. Ranking values were from one to five, with one being the most helpful, and five being least helpful. Time estimates, with a mean rank value of 1.79, were clearly preferred most by subjects. Text messages ranked second with a mean of 2.32 across all clusters except the Non-Changers, who ranked text a close third. Photographs showing actual traffic conditions ranked third with a mean of 2.86, maps fourth with 3.17 and bar-graphs a distant fifth with 4.51. Bar graphs were chosen as least helpful by all clusters. The ranking for third and fourth place varied across clusters. The strong preference for time estimates presented in numeric form suggests that time estimates are the most desirable item to include in a traffic information screen.

In addition, the result that time estimates in numeric form are preferred over time conveyed in a graphic form (such as photographs, map coding, or descriptive text messages), suggests that subjects do not appear to be graphics-oriented. However, based on this screen questionnaire, it should not be inferred that graphic forms of information could not have as much impact as text. We did not show a picture of a jack-knifed truck across three lanes. But under normal commuting conditions of heavy traffic, when commuters are forming a perception of traffic conditions, pictures of traffic do not seem to be as valuable to commuters as numeric time estimates.

Map Orientation

The maps presented in screens were oriented in either a vertical (North up), or horizontal (North to the right) positions. Approximately 87% of the subjects selected the vertical orientation. There was a distinct difference in preference across clusters. The Route and Time Changers as well as the Pre-trip Changers selected the horizontal orientation approximately 20% of the time, while Route Changers and Non-Changers selected it only about 4% of the time.

Use of Express Lane

Subjects were asked if they consider the Express Lane an alternate route. Approximately 60% responded yes. This answer across clusters was approximately 65, 52, 50 and 73% respectively for Route Changers, Non-Changers, Route and Time Changers and Pre-trip Changers. This suggests that Route Changers and Pre-trip Changers are more likely to consider using the Express lanes as an alternate route. This may allow a slightly different screen to be developed for these two clusters.

These results suggest that it is important to include the Express Lane in a traffic information screen designed for commuters traveling on the northern portion of I-5.

Use of a TV-Based Information Service

When subjects were asked if they would use a TV-based information service that provided screens similar to the ones they had just seen, approximately 81% answered yes. This response was quite uniform across clusters: 81, 76, 82, and 86% for Route Changers, Non-Changers, Route and Time Changers, and Pre-trip Changers respectively. This result contrasts markedly with the approximately 25% who answered yes to a similar question on the initial survey. This contrast is likely due to the fact that subjects were answering based on their existing knowledge of traffic information services. In the initial survey, most subject's exposure to traffic information displayed by TV was limited. The graphics questionnaire exposed subjects to actual screens of information. This high positive response is very encouraging with regard to user acceptability of a TV-based traffic information system, especially considering the fact that test screens were designed entirely on assumptions about commuter needs, and test screen information was static (screens were presented on paper, not as changing graphical displays).

Delivery Time for Information

Subjects were asked when during the day they would be likely to receive TV-based information. Almost 100% of the subjects would be reached in the morning between 5 and 8:30 a.m. Approximately 90% would be reached between 5:30 and 8 a.m. When the time window is collapsed another hour to from 6 a.m. to 7:30 a.m., 60% of the subjects are reached. Most Non-Changers (approximately 90%) appear to want delivery of traffic information by 7-7:30 a.m.

This time preference information should be considered only in general terms. A more exhaustive survey should be conducted to accurately identify appropriate delivery timing.

Landmarks Used as Reference Points for Time Estimates

When subjects were asked which landmarks they used to estimate travel time, landmarks given on the test screens were cited most often. The use of landmarks does not appear to be significantly different across clusters.

Since test screens contained landmarks, the results of this question may be skewed towards those landmarks which appeared in test screens. The question of preferred landmarks should be investigated further.

Additional HAR and VMS Considerations

The following section examines the responsiveness of Seattle's motorists to the VMS and HAR system with respect to all phases of our motorist information surveys.

The initial motorist information survey indicated that more than 50% of the motorists have never received information from Highway Advisory Radios (HARs) and about 45% of the motorists have never received traffic information from Variable Message Signs (VMSs). The wording of the question that elicited these results was: "From which media have you EVER received traffic information ?". Given this question, it cannot be assumed that the large number of motorists who have used HAR and VMS use these media frequently. In fact, when motorists were asked what type of medium they would prefer to receive traffic information from, the number that responded VMS or HAR was very low. About 8% of the entire population of motorists that were studied preferred receiving information from VMSs and only 5% preferred receiving information from HARs. In addition, and perhaps more revealingly, over 65% of the motorists obtained "very little help" or "none at all" from VMSs and HARs.

The comments from motorists during the in-depth survey regarding the usefulness and appropriateness of VMSs and HARs converged on the general consensus that the signs were not helpful. Common comments were that the location and placement of the VMSs provided delayed information. Motorists felt that messages relayed by VMS did not give them warning prior to the location of the actual congestion, but rather that congestion messages were delivered when they were already involved in the congestion. Motorists also felt that the message content was not up to date; they questioned the value of what they felt was delayed information.

The in-depth interview also indicated that many motorists do not use HAR, either because either they do not know it exists, had never tried using it, or found better information from commercial radio stations. Nevertheless, motorists in the original survey were enthusiastic about the development of a dedicated, 24-hour traffic information radio station.

Remarks

The in-depth survey described above and the analyses conducted on commuter responses have produced a more detailed picture of the behavior and information requirements of commuters to the metropolitan Seattle area. That picture is one of an extremely complex population, but with definable needs that can be grouped parsimoniously, allowing for concrete implications for the design of motorist information systems. The method employed has generated a wealth of information that would not have been available through use of a standard, highly structured survey and has provided a set of baseline responses that will allow any changes or modifications to existing information systems to be examined for efficacy.

The analyses also raise a set of additional questions for researchers interested in motorist information systems. One question would be with regards to the generalizability of these findings to other commuting corridors. Work is currently underway to extend this method to studies of other freeway corridors in the metropolitan Seattle area. Studies of other major commuting groups using a similar method would allow for comparison of findings and a search for more general principles. These in turn could lead to a set of general guidelines for designing motorist information systems.

The central premise of our work--that commuters cannot be considered as a homogeneous audience for motorist information--has been strongly supported. The method employed in this study has reinforced the commuter groups derived from the cluster analysis of our initial survey, and has focused on these differences to identify aspects of commuters' daily tasks that help determine their use of and response to motorist information.

On July 24, 1989, our project team presented a demonstration to WSDOT and TRAC personnel of motorist information screen design based on preliminary human factors analysis performed during the in-depth survey. These screens were well received and reminded us that perhaps the most significant finding of the graphics part of the in-depth survey was that subjects were significantly more positive towards graphical presentation of motorist information after being exposed to sample screens. Thus, the negative response to graphical media in the initial survey (and positive response to commercial radio) is at least partially due to previous exposure, or lack of exposure, to these media. Initial survey results indicating media preference should be viewed as an interesting "slice in time", rather than a long range finding. While further study of the human factors of motorist message content and design is needed, it appears likely that exposure to positive examples of motorist information will significantly increase public acceptance.

INTERPRETATION, APPRAISAL, APPLICATION

INTRODUCTION

As has already been indicated, the findings reported above can be applied to solve practical design problems central to the development of an Advanced Driver Information System (ADIS) for the Puget Sound area.

There are two major ADIS development thrusts: (1) the collection, design, and delivery of real-time traffic information; and (2) the storage, display, and delivery of dynamic route guidance and vehicle navigation information. The effective delivery of both real-time traffic conditions and route guidance information should together contribute to the achievement of two goals: (1) improved short-term motorist response to incidents and peak hour congestion; and (2) long-term modification of commuter behavior for more efficient use of existing transportation resources. Specifically, there are four aspects of commuter behavior that an ADIS should affect: (1) departure time, (2) means of transportation (buses, trains, car pools, etc.), (3) pre-trip route choice, and (4) on-road route modification.

Presently, WSDOT's Traffic Systems Management Center (TSMC) gathers traffic data via sensors on the freeways, closed circuit television, and police and bus reports. This helps DOT personnel to know almost immediately when and where a backup occurs and gives them a comprehensive picture of the freeway traffic flow. However, delivering this data to commuters in a timely manner and in a form that will actually impact driver behavior is far from a trivial matter. The understanding of commuter decision-making processes provided by our surveys can guide our design of a system which will deliver such information.

For example, central to the delivery of real-time traffic conditions is the issue of how best to convert existing on-road traffic data into useful, effective motorist information. On one hand, the conversion of traffic data into driver information must be rapid enough so that the traffic conditions which stimulated the information are still in effect when the conversion is completed and the information delivered to driver decision points. On the other hand, the conversion must be complex and sophisticated enough so that it produces information capable of impacting the behavior of a sufficient number of drivers to improve the current state-of-affairs. Our survey findings prompt a number of design strategies for a conversion that will achieve both of these goals.

RESPONSE TIME, REAL-TIME, AND EFFECTIVE-TIME

It is difficult to describe the precise characteristics which qualify a system as "real-time," and while ADIS are often referred to as "real-time" systems, they differ in many respects from fully automated control systems. "Real-time" relates to a system's *response time*, the time it takes for the system to react to a stimulus from its environment. Some stimuli call for an "instantaneous" response, for example, there should be no delay between the time you drag your mouse and the cursor moves on the screen. In practice, however, an "instantaneous" response is often neither necessary nor possible. Instead, "real time" requirements for a complex system depend upon the goals of the system and the conditions under which it must operate. Thus, a system to control a power-station boiler may require response to a temperature change in thirty minutes, while a missile control system must respond to a course change in milliseconds.[9] What ultimately matters is whether or not the system is able to improve the environment in which it is operating. For more complex systems, it may be more helpful to think in terms of *effective-time* rather than real-time.

The ADIS situation is extremely complex, making it difficult to determine its effective-time requirements (the response time required to effectively impact the operating environment). For an ADIS, the operating environment is the current traffic conditions of a given transportation system; the environmental stimuli consist of data about incidents, congestion, and traffic flow; and the system response, at least in one sense, is a broadcast or communication. The effective time of that communication--the length of time after which that communication will no longer be appropriate for the state-of-affairs which produced the stimuli--varies with the nature of the particular traffic problem, ranging from a few minutes to many hours. In addition to response time, an ADIS designer must be concerned with the issue of effective broadcast time, that is, the length of time over which a given message can be transmitted and still be effective. The shorter the response time of an ADIS, the longer the effective broadcast time. The longer the effective broadcast time of an ADIS, the greater should be the system's impact on existing traffic conditions .

The ADIS situation is further complicated by the fact that it is not a fully automated control system, particularly in the response mechanism. If the system response is viewed as a broadcast or message, as we have done thus far, than that response alone is insufficient to affect the operating environment. People are a crucial part of the "system response" since traffic conditions are ultimately affected only through the decisions of drivers to modify their behavior. People are even likely to play a role in the ADIS mechanism which gathers environmental stimuli, since this mechanism consists not only of detectors on the road and closed circuit television, but also of reports from police, bus drivers, and traffic reporters. Thus, in terms of actual impact of the operating environment, *human* response is a key component of ADIS response time.

From this perspective, it may be inappropriate to think of an ADIS as operating in "real-time" at all. This does not mean, however, that an ADIS cannot operate in "effective-time." To accomplish this, algorithms for rapidly converting traffic data into motorist information must be based on a thorough awareness of motorist behavior and decision-making processes. This takes us from concerns about system response time to concerns about types of driver behavior to be modified, willingness of drivers to alter that behavior, possible alternatives, and the decision processes of commuters. In short, it takes us from concerns about data to concerns about information and communication.

It is precisely these concerns that our work has addressed, and converting traffic data to driver information is one area in which our findings can be immediately applied.

TRAFFIC DATA VS. DRIVER INFORMATION

No matter how sophisticated the communication technology used to construct an ADIS, it will be ineffective if the information delivered is inappropriate for the driver's situation. An ADIS must rapidly convert on-road traffic data into driver information, yet the design of this driver information must be driven by an understanding of motorist behavior, alternatives, decision processes, and information needs. Within this basic orientation, our work has identified and defined a number of distinctions which must be carefully considered when designing an ADIS. First, there are the types of decisions to be impacted. Assuming that an ADIS will deliver information both at home and on the road, there are four types of commuter choices that we are likely to affect: (1) selection of departure time, (2) selection of transportation mode (buses, trains, car pools, etc.), (3) pre-trip route choice, and (4) on-road route choice.

In addition to types of choices, there are also types of drivers. As stated previously, motorists are not a single homogeneous audience for traffic information, but rather are a mix of complex sub-groups: (a) **route changers** (RC), willing to change routes both before or during their commute, but unwilling to change other motorist behavior such as departure time or transportation mode (20.6%); (b) **route and time changers** (RTC), like route changers but also willing to change departure time (40.1%); (3) **pre-trip changers** (PC), those unwilling to change route while traveling, but willing to change time, route, or even mode prior to leaving their residence (15.9%); and (4) **non-changers** (NC), unwilling to change time, route, or transportation mode (23.4%). Before analyzing specific design strategies for these groups, it is first necessary to discuss some general strategy for converting traffic data into driver information.

A formal process for converting tables of traffic data into driver information that meets the complex informational needs of these driver groups, and does it all in effective time, sounds like a formidable if not impossible goal. Fortunately, ADIS designers have a major advantage over most designers of technical information systems--it is neither necessary nor desirable to impact every driver who receives a given message. The primary goal of an ADIS is to improve system flow. Mass communications such as public relations messages and general information are secondary. This practical emphasis, combined with the fact that drivers are not homogeneous but instead can be classified into distinct behavioral and decision-making types, points to an efficient and effective general strategy for converting traffic data into driver information--isolate the particular type of behavior we are trying to modify and then focus on those drivers who are most likely to alter that behavior.

At first glance, this strategy may appear limited because it seems to ignore large numbers of motorists who are highly unlikely to be affected by particular types of motorist information. In fact, this strategy runs counter to that employed in most technical communication situations, but for good reason. In most technical communication situations, it is crucial to address every possible member of even an extremely complex and diverse audience. For example, the designers of user support information for computer applications must consider both naive and experienced users, and whether the "system" for delivering that support is online or a set of manuals, it would be unsuccessful if only the experienced users were helped. Similarly, a technical proposal would be unsuccessful if it spoke from one engineer to another about technical concerns, but not to the budgetary concerns of more financially oriented reviewers. Usually it is inappropriate to select the most receptive or sympathetic portion of a complex audience and design technical information primarily for that portion. For driver information systems, however, this is precisely the case.

Certainly the audience for motorist information is extremely complex and diverse, but that does not mean it needs to be addressed in the same complex manner as the audience for computer documentation. Given the constraints of dynamic, effective-time information, there is little time for manipulating and delivering motorist information designed to impact the full range of motorists with their diverse personalities, geography, travel needs, social situations, economic status, etc. More importantly, there is no need to do so.

Despite the complexity of their task, designers of motorist information systems have a major advantage over the designers of computer support systems--they do not have to impact all motorists to be successful. Significant improvement in freeway through-put can be achieved by impacting a relatively small percentage of drivers, while an identical change in behavior by 100% could be disastrous. Particularly in route choice, if an extremely high percentage of commuters responded similarly to an ADIS, that would simply move the problem to another portion of the transportation system.

In addition to producing the desired impact, basing the design of motorist information on the needs of targeted sub-groups of drivers is cost-effective as well. For each type of driving behavior, there is a significant percentage of drivers who are not only unlikely to change, but are also less likely than other groups to *receive* the ADIS message. Table 39 shows the percentage of driver groups from our survey who claimed never to have received information relevant to four travel decisions: 1) on-road route selection, 2) pre-trip route selection, 3) pre-trip departure time, and 4) pre-trip travel mode selection. The response indicates that those drivers less likely to make travel decisions that would modify their commuting behavior are also less likely to be aware of available relevant information in the first place. At first glance, an information designer might see the 39.5% of non-changers who claim to never have received information relevant to their pre-trip route selection (compared to 0.5% of route and time changers, 0.2% of before-changers, and 0% of route-changers) as an untapped mine to be targeted for motorist information efforts. One might argue "Clearly the information is there, the other commuter groups are receiving it, so if we can just make these non-changers aware of its existence, we might move them into other, more flexible categories."

Table 39. Percentage of Cluster Claiming Never to Receive Information Relevant to Travel Decisions.

	Route Changers N=744	Non-Changers N=844	Route & Time Changers N=1446	Pre-Trip Changers N=576
on road/route	1.7	9.2	0.0	5.8
pre-trip/route	0.0	39.5	0.5	0.2
pre-trip/departure	7.1	42.9	0.0	0.0
pre-trip/mode	30.6	62.1	34.5	2.3

This argument to direct our energies towards reeducating driver groups would be valid if the primary goal of an ADIS was to impact as many drivers as possible. The primary goal, however, is to improve system through-put, and this can most efficiently be done by impacting a small group of receptive motorists. The educational and communication efforts required to both reach and impact a group which is not only unlikely to modify driving behavior, but claims actually to never have received available information, far outweighs the benefits. This is especially true considering that our work has identified significant groups of commuters who are not only willing to modify driving behavior, but are also eagerly seeking information to help them do so. By targeting these flexible, highly motivated drivers, we can achieve a maximum improvement in traffic flow at a minimum cost in development effort and dollars.

DESIGNING FOR TARGET AUDIENCES

The general issue of how to design motorist information to impact a target audience is closely tied to the type of motorist information at our disposal and our understanding of the behavior and decision-making factors of the target commuters. Differences in commuter behavior are not the only issue. Other factors such as geographic location and timeliness of information also play important roles in the delivery of effective traffic information to commuters. However, commuter characteristics are crucial.

Table 40. Non-Time Changers vs. Time Changers.

Non Time Changers RC/NC				Time Changers RTC/PC
lower	<-----	stress	----->	higher
lower	<-----	female	----->	higher
lower	<-----	response to time pressure	----->	higher
care less	<-----	save time	----->	care more
care less	<-----	reduce distance	----->	care more
care less	<-----	increase safety	----->	care more
care less	<-----	increase enjoyment	----->	care more
prefer less	<-----	info at home	----->	prefer more
longer	<-----	freeway commute	----->	shorter
higher	<-----	household income	----->	lower
higher	<-----	age	----->	lower

We have, for example, identified the RTC and PC groups as highly susceptible audiences for home delivery of motorist information that will alter their departure time. How does this actually help in creating algorithms for converting real-time traffic data into effective motorist information? Based on our survey of Seattle commuter behavior and decision-making, we know a number of way in which the RTC and PC groups tend to differ from the other two commuter groups. Some of these are summarized in Table 40 above. From these and other survey results, we can come to some conclusions about those motorists who are most likely to alter the time that they begin their commute. These conclusions then become the basis for converting traffic data into motorist information.

There are essentially two ways that people can alter their departure time. If their arrival time is flexible, they can delay their departure until after congestion has died down. If their arrival time is rigid, they can judge if there are unusual delays due to incidents or congestion and leave earlier so as to meet their arrival deadline. Time changers (RTC and PC) who commute to Seattle from the north are clearly of the latter variety. They tend to be female; have lower household incomes; have longer, more complex commutes; care more about commute time, distance, safety, and enjoyment; and experience higher levels of stress during their commute. They are people with less control over their working environment and for whom the daily commute is a major component of their day. They worry about arriving on time, and after deciding to change route and departure time their stress increases, not decreases.

Information like this leads to a picture of a significant group of commuters who are under stress to complete their commute at a set time. These people want their information at home. Their commute begins as soon as they get up and they start gathering information through TV (the *PC* group is the highest percentage users of TV information) and radio in an effort to determine if they have to alter their usual pattern of commute. Over a third of the *PC* group is even willing to change mode if necessary, the only group of the four with a significant willingness to make this effort. In fact, time changers care more about *everything* related to motorist information. They also are more likely to receive relevant information at home and to find it helpful. The commute is an important factor in their lives and they are an optimal audience for home delivered motorist information.

This picture of the two groups willing to alter departure time tell us how to speak to them and what they need to know. They are under pressure to complete a complex commute on a rigid schedule, and we need to speak to that need. Most importantly, they need to know commute time information. Ideally, they need to be told what time they would arrive if they left right now under current conditions following their primary route. They also need to know time estimates for alternate routes and alternate modes of transportation, and they need feedback to reduce stress and reinforce modifications to their usual travel routines. Spoken to appropriately, the PC and RTC groups are flexible before leaving the house, and they will change departure times, routes, and even modes of travel (PC) if it is necessary to arrive on time.

SELECTING THE TARGET AUDIENCE

As we have just seen, the issue of who to target is closely tied to the behavior the ADIS designer is trying to impact. For example, if the goal is to spread out the time over which a given volume of commuters uses a particular freeway corridor, then the primary target audience will be commuters who use that corridor and are particularly susceptible to changing departure time. However, if the goal is to divert traffic off a stretch of a freeway, then the primary target audience will be commuters approaching that stretch of freeway who are particularly susceptible to altering route while driving.

Some susceptible commuter groups are quite distinct. Table 41 reemphasizes the startling split in Seattle commuters' willingness to alter the time they begin their commute. Less than 1% of RC and NC (11 of 1,588) indicate a willingness (*frequently* or *sometimes*) to adjust the time they leave for work based on traffic information, as opposed to over 99% of *RTC* and *PC* groups (2,010 of 2,018).

Table 41. How traffic information influences departure time

	Frequently	Sometimes	Rarely	Never Receive
RC	0	0	691 (92.9%)	53 (7.1%)
NC	1(0.1%)	10 (1.2%)	471 (55.8%)	362 (42.9%)
RTC	296 (20.5%)	1145 (79.2%)	5 (0.3%)	0
PC	177 (30.9%)	392 (68.5%)	3 (0.5%)	0
All	474 (13.1%)	1547 (42.9%)	1170 (32.4%)	415 (11.5%)

In Table 28, the significance of using multivariate techniques such as cluster analysis to identify commuter sub-types becomes apparent. If we look at the combined data for all surveyed commuters, there appears only to be an extreme diversity in commuters' willingness to alter departure time based on traffic information received at home. Based on our awareness of commuter types, however, we can focus on a carefully defined group of commuters and study those factors which influence their departure time. Then, if we can deliver information that speaks to these factors, we can be confident of a high degree of success in influencing the time when they begin their commute.

We have looked at just one of several possible commuter groupings relevant to ADIS design. Thus, non-time changers (NC and RC) vs. time changers (RTC and PC) is one way that commuters can be grouped when designing information to impact departure time, but it is not an appropriate grouping for all motorist behavior. "En route changers" (RC and RTC) vs. "Non-en route changers" (NC and PC) is another interesting grouping which becomes important when we are considering how to design motorist information to impact on-road route modifications in response to incidents and congestion.

Thus the general strategy advocated here--targeting information for those motorists most likely to be affected--does not mean that the same group will be targeted for all types of motorist information in all types of driving situations. Despite this focused approach, a single successful ADIS will meet the needs of a wide range of motorists under varying conditions and stages of travel. This does mean, however, that a single integrated motorist information system will consist of carefully designed information modules targeted to address particular commuting decisions of carefully studied and defined subgroups of receptive commuters. As we know more and more about commuter groups, we discover more and better ways to design motorist information that meets their needs.

CONCLUSION

The creation of a mechanism for gathering real-time traffic data is only the first step in the creation of an ADIS. Subsequent steps must be directed towards (1) isolating the particular driver decision to be affected by each message; (2) identifying those drivers who are highly flexible and motivated on that issue; (3) determining on what basis their decision is made; (4) creating an algorithm for converting on-road data to information that addresses this decision process; (5) determining where the decision is made; and (6) delivering to that point, at a time when it can be used, information designed to meet the decision-making needs of the targeted drivers.

The process of converting traffic data to motorist information can be simplified by limiting our design considerations to those sub-groups of drivers who are most likely to be impacted. Our findings have significantly contributed to the application of this strategy. For example, the departure time of the "pre-trip changer" and "route and time changer" groups is the single commuter decision most influenced by existing traffic information. For home delivery of motorist information, therefore, we need to focus on the "time changers." Not only is the time changers' behavior before leaving most flexible, they are also more likely to access available motorist information on this topic. For this group, arrival time and reduction of stress are key. If we can deliver to the time changers' home the travel time for various routes to downtown, and provide feedback mechanisms while en route, then our efforts to impact departure time decisions are going to be successful.

CONCLUSIONS AND RECOMMENDATIONS

The following are related conclusions and recommendations derived from our work.

THE SURVEY

Conclusion #1

The methodology described above is extremely successful at gathering data on commuter behavior and decision processes.

Previous studies have surveyed general population [8] or Central Business District workers [10] or households [11], but ours focused directly on the population in question--commuters traveling a selected corridor, contacted near the end of their trip while still in their cars. This resulted in a high response rate; an extremely large, relevant subject pool; and an extensive, complex data set.

Conclusion #2

The analytical methods described above, particularly *cluster analysis*, are extremely successful at leading us beyond descriptive results to deeper, more inferential analysis of traffic management data.

Our analysis went beyond that of previous studies, providing a richer picture of motorist behavior. For example, a previous study [11] found that "departure time decisions are... much more flexible than are mode choices." While our study confirmed this general conclusion, cluster analysis allowed us to take it much further. Actually, there are two types of commuters for whom both departure decisions and mode choice are extremely inflexible, a third type for whom departure time is extremely flexible and mode choice extremely inflexible, and a fourth type for whom departure time is extremely flexible and mode choice is somewhat flexible (in fact this fourth type is more likely to change mode than they are to change route while on the freeway). Cluster analysis enabled us to define and explore previously unknown commuter types.

Recommendation #1

Apply the methodology and analytical methods of this survey to other corridors, locations, and situations.

Only by building up a body of comparable data for numerous corridors, locations, and situations can we distinguish generally applicable commuter characteristics from those which are dependent on geography, date, and other local variables. This knowledge is essential to efficient development of traffic management strategies.

COMMUTER TYPES

Conclusion #3
Commuters are not a single, homogeneous audience for motorist information.

Rather, commuters are a complex audience with differing information requirements related to differing geography, socio-economic status, driving tendencies, stress levels, personality types, etc. At any given moment, a particular message can be "right" for one commuter, "wrong" for another, and meaningless to a third.

Conclusion #4
Distinct, stable sub-groups of commuters can be identified, based on driving behavior, decision-making, and information needs.

As described above, we identified four commuter groups, each of which is more or less likely to be influenced by motorist information, depending upon the type of driving behavior to be modified. These groups remained stable for related findings not used in the cluster analysis, as well as for in-depth survey findings.

Conclusion #5
Commuters who are less flexible about a given driving decision are also less likely to be aware of available motorist information that could impact that decision.

While this conclusion holds for all commuter types, it is most evident in the *non-changer* group, which not only is least likely to modify their driving behavior, but also is most likely to claim they have never received relevant traffic information.

Recommendation #2
Use the identification of driver groups to tailor motorist information to those groups most likely to be impacted.

The goal of a motorist information system is to improve traffic flow, not to be equally useful to all drivers at all times. This improvement can be achieved by affecting a targeted subset of commuters. To efficiently achieve this improvement, designers of motorist information systems should guide complex design decisions such as what to say, how to say it, and how and where to deliver it, by targeting those commuter sub-groups who are most susceptible to the information.

PRE-TRIP INFORMATION

Conclusion #6
Commuters are dramatically split in their departure time flexibility.

Conclusion #7
The single most flexible driving decision is the departure time of the *route and time changer* and *pre-trip changer* groups.

Nearly all of the commuters from these two groups (99.6%; N=2018) reported that they frequently or sometimes change the time they leave based on traffic information received at home.

Conclusion #8
The single least flexible driving decision is the departure time of the *route changer* and *non-changer* groups.

Nearly all of the commuters from these two groups (99.3%; N=1588) reported that they either rarely change the time they leave or never receive information relevant to this decision at home.

Conclusion #9
Most commuters are flexible about changing routes based on traffic information received prior to departure.

In three of the four commuter groups (*route changer, route and time changer* and *pre-trip changer*), 80% of the commuters reported that they frequently or sometimes change their route based on traffic information received at home.

Conclusion #10
Commuters are receptive to traffic information delivered at home.

The initial survey found that most commuters prefer their motorist information at home. The in-depth survey found that commuters have the time and inclination to seek motorist information an average of three times before leaving the house.

Recommendation #3
Place a high priority on home delivery of motorist information, particularly related to impacting departure time.

Recommendation #4
Target home delivered motorist information for specific types of commuters, based on the driving decision to be impacted.

For example, by impacting those commuters identified as susceptible to altering departure time, we could spread out the commute and reduce peak congestion.

RELIABILITY OF MOTORIST INFORMATION

Conclusion #11
Commuters question the credibility of motorist information.

This was a prevalent theme of survey comments which was supported by subsequent findings indicating that commuters generally do not find existing messages credible.

Conclusion #12
Having modified their behavior, commuters do not know whether or not they have made the correct decision.

Having decided to use an alternate route, commuter stress increases, rather than decreases. In addition, nearly one-third of the commuters indicated that they had no way of telling if their choice to use an alternate route was correct or incorrect , with the remainder indicating that if they did receive information confirming or refuting their choice to use an alternate route, they received it too late to be of use.

> #### Recommendation #5
> **Include a feedback mechanism in any motorist information system.**
>
> Commuters require verification that information is reliable and timely. Without feedback, for example, a driver cannot know whether or not a congested alternate route was actually an improvement over the abandoned primary route. Informing commuters of the benefits of their decisions reinforces those decisions and builds needed commuter confidence in the system. This is especially true for on-road delivery mechanisms such as HAR and VMS.

ON-ROAD INFORMATION

Conclusion #13
On-road route changers are fairly flexible, but less flexible than pre-trip changers.

Seventy percent of the commuters in the *route changer* and *route and time changer* groups said they frequently or sometimes change their route based on traffic information received while on the freeway.

Conclusion #14
Commuters are not receptive to traffic information delivered on the freeway.

Less than 3% of the commuters in the *route changer* and *route and time changer* groups prefer to receive their traffic information while on I-5. Even though these two groups tend to alter their route while driving, 58% prefer to receive traffic information at home.

Conclusion #15

Commercial radio is the preferred medium for delivery of on-road traffic information.

Ninety four percent of commuters in the *route changer* and *route and time changer* groups report that they are helped by traffic information delivered via commercial radio. Only 1% claim never to have used commercial radio to receive on-road traffic information.

Conclusion #16

HAR and VMS are not generally perceived as helpful.

Only 37% of commuters in the *route changer* and *route and time changer* groups report that they are helped by traffic information delivered via VMS, and only 31% by traffic information delivered via HAR. Furthermore, 44% of the commuters from these route changing groups claim never to have used VMS and 53% never to have used HAR. During the in-depth survey, common complaints were that VMS were poorly located, did not give sufficient warning prior to actual congestion, and that message content was not relevant or up-to-date. Common problems cited about HAR were that commuters did not know it existed, had never tried using it, had difficulty receiving it, or found better information from commercial radio stations.

Recommendation #6

Place high priority on improving on-road information delivery mechanisms.

On-road delivery mechanisms are crucial both as feedback mechanisms and as a means of encouraging route changes following an incident. While HAR and VMS were not seen as effective (and even commercial radio was most popular among those least likely to change routes), the in-depth survey showed that through exposure to positive examples, commuters response to delivery media can be markedly improved.

Recommendation #7

When designing and delivering on-road motorist information, target those commuters who tend to change route while driving.

Overall, commuter receptivity to on-road information is far less positive than that for pre-trip information. This makes it even more important to target those commuters most likely to be impacted in order to design and deliver effective on-road traffic information.

<u>Recommendation #8</u>

Through the use of an *integrated* information system, coordinate home and on-road messages based on delivery location and motorists' need for feedback and reinforcement.

Motorist messages are both dynamic and interrelated. This means that constantly changing conditions require drivers to continually update and confirm their concept of traffic conditions through access of related messages from multiple media at various locations and times. On-road messages should be tied to the motorist decisions made at the location where they are delivered, and new locations should be developed both at key decision points and at locations where feedback is sought. Thus, messages should be seen not only as isolated events, but also as one of a series of communications that a motorist can receive during a single trip.

<u>Recommendation #9</u>

Improve on-road message content.

In particular, balance the trade-offs between generality and specificity of the message, and between reason vs. task information. More research is needed in this area.

<u>Recommendation #10</u>

Keep on-road messages relevant to impacting particular driver decisions, or to feedback and reinforcement of those decisions.

Motorists need to be convinced of the relevance and usefulness of on-road traffic information. If no information is available that is intended to impact or reinforce a specific driving decision, avoid "filler" messages such as "Buckle up."

<u>Recommendation #11</u>

Incorporate an indication of the timeliness of the message into on-road motorist information.

<u>Recommendation #12</u>

Integrate on-road delivery mechanisms more closely with real-time gathering of traffic data.

Recommendations #8, #9, #10, and #11 will only be effective in improving on-road information systems if on-road messages are developed through a rapid yet effective conversion of existing real-time traffic data into useful motorist information.

IMPLEMENTATION

1. To implement Recommendation #1 above, we should extend our survey of commuter behavior and traffic information beyond the north I-5 corridor of Seattle to the rest of the Puget Sound area. By studying two additional corridors, the Seattle inbound commuters on the southern I-5 corridor and the east/west commuters on the I-90 and SR520 corridors, and by using the survey methodology and instrument developed in our initial work to assure comparable data, we would produce a complete analysis of Seattle freeway commuter behavior and decision-making. In addition, because this information has applicability beyond the development of motorist information systems, it should be analyzed and shared with state agencies, lawmakers, and public groups, to help shape state transportation policy

2. To implement Recommendation #2 above, we should develop a front end/interface to the TSMC's system for gathering and displaying real-time traffic data. This front end should be PC based, and should be capable of converting existing traffic data into information tailored to impact various commuter groups and their choice of route, mode, and time of commute. Throughout development, formal usability testing should occur to assure that the user interface displays motorist information in a form capable of impacting the specific driving decision of a targeted commuter group.

3. To implement Recommendations #3 and #4 above, we should select and develop home delivery mechanisms (e.g. dedicated cable TV, teletext, dedicated radio, home networked computer service, telephone system) for delivering the information produced by the system front end (2.).

4. To implement Recommendation #5 above, we should use on-road motorist information to provide feedback and confirmation of reliability of home delivered motorist information. Post-commute delivery at work could also be effective.

5. To implement Recommendations #6-#12 above, we should: (a) develop and implement state-wide guidelines for HAR and VMS based on these recommendation; (b) conduct additional research on motorist response to traffic messages, varying not only message types, but media as well; and (c) explore methods for linking and coordinating the mechanisms by which we deliver driver information both on-road and at home.

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APPENDIX I:
TOWARDS A USER-BASED MOTORIST INFORMATION SYSTEM FOR THE PUGET SOUND AREA:

A STATE-OF-THE-ART REVIEW

Background

As in many larger cities, the traditional solution to traffic congestion in the Puget Sound area has been to build bigger and better roads. Yet despite recent construction, the central Puget Sound region suffers today from the sixth worst traffic congestion in the nation. Currently, no plans exist to construct additional freeways, and congestion is expected to increase dramatically throughout the coming decades. To avoid the high financial and environmental costs of building new freeways, the Washington State Department of Transportation (WSDOT) is pursuing several transportation system management initiatives designed to increase the efficiency of existing facilities. This state-of-the-art review is the first stage of an initiative to combine improved motorist information with new communication technologies so that drivers will use Puget Sound freeways more efficiently.

Problem

One way to alleviate traffic congestion and to use existing roadways more efficiently is to modify commuter behavior. A change in commuter behavior can be brought about by providing motorists with appropriately packaged and delivered, up-to-the-minute information that will allow them to make more effective pre-trip and en route driving decisions (OECD, 1987). An aspect of this approach is to examine human factors, such as personality and vision, which influence how commuters perceive and interpret traffic related information. With improved, user-based content and delivery of freeway traffic information, drivers can make decisions that will result in fewer delays for the individual motorist and an overall improvement in traffic flow.

Significant improvement in traffic flow through motorist information can only be achieved if the mechanisms for delivering that information are developed as an integrated system that is responsive to users' needs and perspectives. In turn, this can only be achieved if we obtain a better understanding of commuters. Thus, current problems to be overcome include not only issues relating to the selection and use of communication technologies and the generation of information, but also issues of audience definition. In addition, we must better understand the relationships between the technologies for information delivery information and the characteristics of the commuter.

Motorists are not a homogeneous group; rather, they are an extremely complex and diverse audience for driver information. Before we can design and implement an effective motorist information system, we must first answer some questions: What groups constitute the users of a particular freeway system? Which of these groups are most susceptible to varous types of motorist information? What travel decisions do these groups make? On what basis do they make them?

Where do they make them? How do we best present information to the various motorist groups? What will be the impact on traffic as a whole if a particularly susceptible group is influenced by motorist information? Which types of information are most appropriate for various information systems? Until now, the complex nature of motorists as an audience for information has been an extremely neglected topic.

In addition to the nature of the driving audience, there are problems relating to the various types of motorist information, the appropriate mechanisms for presenting each type, and the appropriate places and times for delivering information. An integrated information system should provide motorists with information that will influence their decisions on mode of travel, departure time, and route choice. Pre-trip information can assist drivers in making mode choice decisions, whether short-term, involving a single trip, or long-term, involving a permanent switch to an alternate mode of transportation. Pre-trip information can also influence motorists' departure times. Ultimately the adjustment of mode choice and departure time will result in a lower peak demand for the roads, easing the congestion of rush hour traffic.

Route choice information, provided both pre-trip and en route, can persuade motorists to choose an alternate route through presentation of information on current delays, incidents on a given route, and traffic flow and description of alternate routes. Once an alternate route has been chosen and the driver is en route, route guidance must provide easily understood directions to guide motorists either to their destination or back to their regular route. The use of alternate routes will lessen the demand on congested roadways, resulting in smoother overall traffic flow.

Although many newly developing technologies are capable of providing information to motorists, our approach is not only to discuss the relative benefits of a number of these technologies, but also to discuss the potential impact of these technologies on the human as a decision-making commuter.

Research Approach

This state-of-the-art review focuses on previous work relevant to transmiting behavior-modifying traffic information to motorists in a manner that best meets their complex information needs. To implement a successful information system, one must thoroughly understand the population using the system. Therefore the first portion of this review is devoted to an examination of surveys that have been administered to determine drivers' responses to traffic information and other influences on route selection. Methodology as well as results of these surveys is discussed since the next stage of this initiative to improve Puget Sound motorist information was to conduct a motorist information survey of Puget Sound commuters.

After covering previous relevant surveys, this state-of-the-art review examines the various media that are currently being used, or have the potential for being used, to provide effective traffic information to motorists. Motorists may seek information either prior to or during their journey. Thus, this second portion of the report is divided into two sections, one dealing with pre-trip information sources and the other dealing with in-vehicle information sources. Both sections are subdivided so that each information medium is dealt with individually. The section on sources of pre-trip information examines news bulletins, telephone, television (including graphics and teletext), and microcomputers. The section on sources of en-route information examines signs (static and Variable Message), in-vehicle navigation systems, radio (commercial and dedicated systems), and cellular telephones.

The research reported in this review was chosen for its applicability to the traffic information problems in the central Puget Sound region. The amount of detail in each discussion varies with the applicability of the information. In a number of cases, human factors research related to particular information sources is described to provide the reader with additional technical background, and because these issues are central to the creation of an effective, user-based motorist information system.

Traffic Information and Route Selection Surveys

This section focuses on surveys that have investigated either drivers' route choices or drivers' opinions on traffic information dissemination. The surveys focused on here were selected based on a review of relevant surveys performed over the last 25 years. The findings of the older studies are not always relevant to the problems currently existing on the roads of the Puget Sound region, however some of the survey methodology used in the older studies provided useful information for future surveys including our own.

Survey Methodology: An international search to identify all recent surveys administered on the issue of motorist behavior led to a focus on the methodology of 12 surveys conducted by public agencies or universities between 1963 and 1987, in Texas, California, Sweden, and England. All of the studies were administered in urban areas and had sample sizes ranging from 25 to 2,971. An examination of these surveys helped to identify certain aspects of survey methodology that beginning surveyors should be aware of. Table 1 overviews the methodology of these surveys, focusing on the topics of sample size and administration methods,sample generation methods, and the statistical techniques used to analyze the data.

Table 1. Summary of Survey Methodology

Agencies	Sample Size	Sex, Age, Income Distribution	Sampling Method Generation	Administration
Stanford Res. Inst. (3, 4)	30 drivers	19 M, 11 F; Age, Income NG*	Employees from S. Palo Alto	Unstructured intervie
Stanford Res. Inst. (3, 4)	25 drivers	Sex, Age, Income NG*	Employees from S. Palo Alto	Structured interview
Stanford Res. Inst. (3,4)	150 drivers	All male; Age, Income given	Residence in given block	Structured interview
Texas Trans. Inst., Texas A & M (5)	18 drivers in each survey	Sex, Age, Income NG*	Not given; naive about freeway system	In-car interview
Transport Studies Unit, Oxford University (6)	9 homes, 32 homes	Sex, Age, Income NG*	Maximized range of car use, trip purpose, household characteristics, not representative	Unstructured in-deptl home interview
LA City & County, CA, Highway Patrol & DOT (7)	400 drivers	58% M, 42% F; Age: 18-20=5%; 21-40=67%; >40=28%; Income NG*	Random list of computer generated phone numbers	Structured phone interview
Trans. Res. Board, Houston, TX (8)	843 drivers	Sex, Age, Income NG*	License-plate survey at 6 sites on 3 freeways	1-page mail-in questionnaire
British Dept. of Trans. (9)	~ 508	Sex, Age, Income NG*	Volunteers at destination sites	Not given
Lund (Sweden) Inst. of Technol., Dept. Trans. Pl & Eng. (10)	691 homes 830 drivers	Sex, Age, Income NG*	Not given	Home interview/ mail questionnaire
UCLA, Inst. of Trans Traffic Eng. (11)	304, half at each	76% M, 24% F; Mean age 37; Income NG*	Volunteers at sites	On-site interview
UCLA, Inst. of Trans. Traffic Eng. (11)	2971 drivers; groups of 250	48% M, 52 % F; Age: <35=61%, 35-49=24%, ≥ 50=16%; Income NG*	CA driver's license; recruited to represent population	Questionnaire
Texas Trans Inst., Texas A & M (12,13)	505 drivers	68% M, 32% F; Age NG*; Income given	Employees of 17 groups	On-site interview; 32 in homes, 176 in car

* NG = Not given but researcher claims sample represents population

Sample Size and Administration Methods: The interdependency of sample size, budget, and data analysis techniques influences a survey's design and this interdependency cannot be ignored. Transportation surveys have been administered in person (home, car, and office), by phone, or by mail. Cost and sample size are related to survey administration method: a larger sample size requires a less personal administration method if costs are to be controlled.

The surveys listed in Table 1 exemplify a large range of sample sizes and methods of survey administration. Because in-person interviews are costly, sample sizes are frequently small when personal interviews are conducted. Stanford's 1963 and 1964 personal interviews used sample sizes of 25, 30, and 150 drivers [3,4]; three on-road interviews by the Texas Transportation Institute each used 18 drivers [5], and an Oxford University study conducted two sets of in-person surveys in 9 and 32 homes respectively. When larger sample sizes are used, surveys are often conducted by mail. For example, sample sizes in the mid-range [6, 7, 8, 9, 10,11, 12, 13], from 304 to 843 drivers, have included both personal interviews (at destination sites, at home, or by telephone) and mailed questionnaires. Sample sizes for mailed questionnaires ranged from 505 drivers in a 1971 Houston and Dallas survey to 843 drivers in a 1984 Houston survey [10, 11, 6]. The Houston survey was limited to a one-page questionnaire, perhaps because costs for data analysis, printing, and mailing increase with sample size. In contrast to the general trend that larger samples are surveyed with mailed questionnaires, UCLA researchers [11] conducted in-person interviews with a large sample size of 2,971 by interviewing large groups of drivers (250 drivers per group).

Sample size may also influence the conclusions available to the researcher and the generalizability of the results. If one plans to use inferential statistics, one must balance the *a priori* alpha level with the sample size; if the sample is too small the variance may be quite large, thus decreasing the power of the design and reducing the chance of obtaining significance at an acceptable alpha level. Many formulas exist for determining sample size if population variance can first be ascertained. Other methods for determining sample size are based on the statistical techniques to be used. For example, Ahlgren and Walberg [14] state that 20 subjects are needed per independent variable if regression analyses are to be used. Some traffic researchers have been sensitive to this issue; a 1987 Los Angeles telephone survey of 400 drivers based its sample size decision on a worst case sampling error of ± 5% with 95% confidence [7].

As the preceding review indicates, the choice of sample size involves tradeoffs. A small sample size allows for extensive questioning and personal administration methods; however, a larger sample size, while restricting the number of questions and the administration methods, increases the likelihood of greater external validity.

Sample Generation Methods: After sample size and administration methods have been determined, one must carefully design a method for generating the sample. Although a random sample is preferred, some designs may require random selection from selected sub-populations. For example, to identify the 400 driver sample for a telephone interview, a 1987 Los Angeles survey team developed a list of 2,000 valid telephone numbers from a random list of computer generated numbers for a given set of area codes [7]. In contrast, Houston's 1981 driver survey identified its sampling frame for a mail survey through a license plate study of a specific freeway section [8].

As shown in Table 1, not all of the survey sampling frames appear to have been as carefully generated as these examples. However, if the survey's sampling frame is to accurately reflect the population in question, the sample must be generated in a manner that creates a sample representative of that population. For this reason, many researchers use random sampling, realizing that attempts to stratify samples can actually create sampling biases.

Subject Characteristics and Questionnaire Content: The characteristics of the subjects may affect the validity of the survey findings. While researchers may be quite clear about what information they wish to gather, they must be certain to identify variables that initially may appear to be irrelevant yet that ultimately may be the basis needed for interpreting other data. Specific subject characteristics that may be regarded as demographic or subject descriptor information may actually become critical variables for drawing inferences as well as for comparing results across studies. In any survey, subject classification variables such as age, gender, and income distribution may correlate with other variables the survey is examining; such variables may help the researcher interpret data patterns as well as allowing other researchers to compare their findings. Motorist behavior survey literature is inconsistent in its collection of data on subject characteristics (see Table 1). While difficult, it is crucial to identify all critical subject variables. For example, a surveyor seeking information of drivers' responses to road sign messages needs to include questions assessing subjects' visual acuity so that the relationship of vision to driver preference for road signs can be determined.

Statistical Analysis: Once the data have been collected, investigators conduct some type of statistical analysis, be it descriptive or inferential. In the studies cited here, few inferential statistics have been used, often because the data collected did not lend themselves to inferential analysis. Unstructured interviews with open-ended questions create varied responses that may be difficult to quantify. Additionally, many of the responses in interviews and in written questionnaires represent nominal data that violate the assumptions of many inferential statistics. Thus, most of the motorist surveys report only raw data or response frequencies; occasionally correlations or Chi square analyses were used [3,4]. The Lund University study did conduct a factor analysis of 14 variables that generated 5 factors; the analysis proved to be fairly stable in dividing the sample [10].

In summary, past statistical efforts have often been limited to descriptive analyses. One should realize, however, that statistically more powerful techniques are often required to achieve the goals of a motorist survey, and that innovative application of these techniques can both enhance the external validity of the research design and increase the generalizability of the findings.

Survey Findings: The three main categories of survey findings reveal drivers' attitudes about:

- Travel time, delay, congestion, and the use of alternate routes.
- The accuracy of the traffic information being provided.
- The content of the traffic message and the manner in which content is presented.

These categories form the basis for the following discussion.

Time, Delay, Congestion, and Alternate Routes: The findings in Table 2 on travel time, delay, traffic congestion, and use of alternate routes result from studies done both a long time span and a wide geographical and cultural span. However, certain similarity of results from surveys conducted across time and country provide insights about concerns that Puget Sound area drivers may be expected to express. Cocern with amount of delay, congestion, and time spent travelling appear throughout these studies.

Drivers' attitudes about time appear markedly similar throughout the studies. In the 1964 Palo Alto study, drivers said that time was the most important factor in their choice of a route to work. Safety, congestion, distance, and ease and comfort of the drive were all considered less important factors in the choice of a route to work; interviewers also asked about scenery and operating cost, but found that neither was considered of much importance to commuters (Anderson et al., 1964).

Similarly, in the 1971 Houston study, drivers stated that they were apt to divert from a chosen route if they knew about congestion on the route and if a suitable alternative was available, but were even more apt to divert if pressed for time (Dudek, Messer, and Jones, 1971). Time, rather than distance, was the deciding factor. In 1979 in Reading and Oxford, England, drivers indicated that, although they attempted to minimize both time and distance, they would increase the distance they traveled in order to decrease the travel time (Carpenter, 1979). Time, again, was the more important factor. In addition to time and distance, other factors such as congestion, ease of driving, and number of intersections entered into the route decisions of these drivers. The drivers used routes that they perceived to be the fastest and most direct to their destinations; some indicated that they went through town to save time, while others indicated that they stayed on the motorways to save time.

Based on findings in the 1960s and 1970s regarding the value drivers place on time, investigators in the 1980s have assumed that time is important to drivers, and have further investigated time issues. In the 1984 Houston study, drivers, on average, defined a "major delay" as being 23 minutes or more, while a "minor delay" was defined as 8 minutes or less (Huchingson et al., 1984). Houston drivers said they would divert from a freeway to an alternate convenient service road if they were delayed 5 to 6 minutes. Apparently even a minor delay required more time than drivers were willing to spend. The 1987 Los Angeles study did not query drivers as to the length of delay that would cause them to divert; however, the average delay drivers reported was 18 minutes. Furthermore, Los Angeles drivers indicated that they would divert from the freeway for stop and go traffic. Additionally, 71% of the drivers knew of an alternate route to take (Shirazi et al., 1988).

Time and route diversion questions in Los Angeles revealed information about drivers' desire for guidance; when Los Angeles drivers needed to divert from the freeway, they wanted guidance that showed them an alternate route, and they wanted the option as to whether or not they should take that alternate route (Case et al., 1971; Shirazi et al., 1988). This desire for guidance on an alternate route leads to the next group of findings on drivers' attitudes about the accuracy of the traffic information they receive.

Accuracy of Traffic Information: Numerous studies have indicated that drivers have little confidence in the accuracy of the traffic information they receive. For example in 1987, Los Angeles drivers stated that if they were provided with accurate information and a shorter route to their destination, they would be more likely to divert from the freeway (Shirazi et al., 1988). Drivers' opinions about the accuracy of information provided by any particular medium was not tested in the 1987 study. However in a 1971 Los Angeles study, drivers viewed radio broadcasts as more up-to-date than VMS (Case et al., 1971). The 1979 study in Reading and Oxford, England, found that drivers were of the opinion that British radio information was not timely enough to be accurate. Drivers indicated that they would prefer a system of local broadcasts similar to those used in Germany (Carpenter, 1979).

Continuing with survey results related to the traffic information problem, the final group of findings concern both the content of traffic messages and the media used to present them.

Media and Content: Several studies concerned with traffic information have concentrated on radio and VMS media, with inconsistent results. The majority of respondents to the 1971 Los Angeles study preferred VMS to radio as a medium for presenting traffic information: VMS messages were seen as more easily understood, causing less distraction, improving driving, and easing driver frustration (Case et al., 1971). In contrast to the 1971 findings, the 1987 Los Angeles study found that radio broadcasts cause more route changes than any other medium (Shirazi et al., 1988). Of the surveyed drivers, 68% wanted continuous radio reports. When asked about telephone use, 53% said they would like to have a traffic information telephone number.

The 1971 Houston and Dallas survey results may shed light on the apparent attitude shift over time in Los Angeles. The findings indicated that 45% of the drivers preferred real-time information via radio and 45% preferred real-time information via VMS (Dudek et al., 1971a; 1971b). Although equal numbers of drivers preferred radio and VMS, there was a significant correlation between drivers' preferred medium, preferred location, and preferred time for receiving traffic information. Interestingly, those who preferred radio preferred to receive information before they began their trip or on the major streets before entering the freeway. Those who preferred VMS information preferred receiving their information on the major streets and at freeway entrance ramps. (Note that there was no preference for information on the freeway.)

Beyond examining drivers' preferences about media, studies have also examined drivers' understanding of traffic messages. Interestingly, drivers' beliefs about the clarity of the messages may not always coincide with actual understanding. The 1971 Los Angeles study found that, although drivers thought they understood complex radio messages, they actually did not (Case et al, 1971). However, the 1983 San Antonio study found that drivers could follow complex radio messages if the messages were structured properly (Huchingson et al., 1984).

Many studies have also examined message structure and style. The 1983 San Antonio studies found that a terse, complete sentence, message style was most effective in radio broadcasts. Neither a staccato style, with incomplete sentences, or a conversational style, with extra information, was as effective. Instructions were further improved by including information such as landmarks and the number of traffic lights between turns (Huchingson et al., 1984).

The 1971 Los Angeles study reinforces some of the 1983 Texas findings, though for a different medium. The Los Angeles study (Case et al., 1971) found that the content of VMS messages should be simple and short, and should provide information the driver may act on. The content order should be as follows: the identification of the blocked lane(s); the distance ahead to the blockage; the reason for the delay; and the location of the blockage by ramp or interchange name. The 1979 Oxford and Reading Study found that drivers condense route information into lists, even information from maps; the study recommended that radio messages and signs should format route information as a list (Carpenter, 1979).

Summary: Traffic Information and Route Selection Surveys: As the preceding discussion indicates, survey methodology has a major impact upon the type of data collected and thus upon survey findings. For example, the choice of sample size involves tradeoffs: a small sample size allows extensive questioning that cannot be done with larger sample sizes; in contrast, a larger sample size, while restricting the amount and time of information that can be sought, produces information that can be generalized. Choice of sample size thus impacts the type and extent of questions to be included in the survey. Sample size and other sample characteristics are related to the method used to generate the sample and to the method that will be used to administer the survey. If the survey sample is to accurately reflect the driving population in question, the sample must be generated and administered in a manner that creates a sample representative of that driving population. The data collected can only be as valid as the sample from which that data are collected.

The findings reviewed here provide indications of the topics to be addressed in a survey of motorist behavior and attitudes. Time is a major concern of commuters. Surveys should examine the relationship of time to the drivers' tolerance for delay and congestion, and to the drivers' willingness to take an alternate route. Secondary concerns of commuters should not be neglected, however. A survey should contain questions that solicit commuters' opinions about accurate, real-time information, as well as preferences for message content, location and timing of message delivery, and preferences for the media used to present the message.

Until now, statistical analysis of traffic survey data has been limited to descriptive analyses by the categorical nature of the data assessed. However, our understanding of drivers and the driving experience can be increased through the use of inferential statistics, as well. Given the complex nature of the audience for traffic information, it is important that we use all the tools at our disposal to understand that nature. This understanding will lead to more effective designs for motorist information systems.

Motorist Information Systems: Pre-Trip Information Sources

This section of the state-of-the-art review and the following section, "Motorist Information Systems: En Route Information Sources," explore the media that may be used to deliver information to drivers. Pre-trip information can enable motorists to make effective decisions about the mode of transportation they will use and the time they will depart.

Even with the relatively ad hoc information systems that have evolved, motorists have a number of media available to assist them in planning driving strategies before they begin a trip. The discussion in this section of the report covers media that either currently provide pre-trip strategic information, or have the potential for augmenting current systems as a source of pre-trip strategic planning information. The focus here is on newspaper, radio, and television news bulletins; telephone information services; and teletext and graphic presentations on television.

News Bulletins: The news media are a fairly effective means of transmitting certain types of traffic information. Newspaper, radio, and television news bulletins disseminate information which can help motorists prepare driving plans. The audience for this type of information is very broad, and therefore the information provided is fairly general in nature. This method of transmitting information is especially useful for events with advance warning, such as construction projects, weather related problems, or special events. For example, local Seattle area newspapers regularly cover construction projects and their impacts on the traffic system. The Seattle Times periodically displays a picture of the downtown freeway system and highlights the construction projects underway.

Morning radio and TV reports tend to focus on trouble spots, warning drivers to avoid these and occasionally recommending alternate routes. Known problem areas (e.g., I-90, SR 520, I-405 S-curves) are given regular coverage, but receiving information on other areas is a haphazard proposition. Presentation on radio tends to be far superior to that on TV, especially considering the potential of television for visual presentation of traffic information. Morning KING TV traffic reports, for example, are essentially a radio report with a standard, static picture of I-5 and the reporter's face in the corner of the screen. For this reason, a considerable portion of this section is devoted to enhancement of graphic presentation of traffic information.

Television and Screen Display of Traffic Information: Televised traffic information can be delivered in the form of text, graphics, or pictures, or as a combination of all three. Effectively combining text, graphics, and pictures is challenging, and few systems have attempted this combined format. Most state-of-the-art systems are a compilation of computerized traffic congestion data translated to a graphic display map. This real-time, graphic approach allows volumes of congestion information to be processed and displayed in a manner understandable to most viewers. The system's advantage is its ability to change the display with each new bit of information; thus, the information is easily updated to keep pace with changing conditions. Because such systems usually cover a large area, however, the information is generally limited to major roads and is difficult to personalize. In the future, more sophisticated screen displays will be needed to meet this and other difficulties.

To be televised, this type of system requires two major steps: first, computers must receive data from sensors on the road and translate the data into a meaningful display; second, the computer-generated display must be projected onto a television screen. This section focuses on the second of these steps, particularly issues related to screen display.

Teletext systems are one option. These systems combine text and graphics by scrolling text over graphic displays. Teletext could be used to display and transmit traffic information by several methods. At the simplest level, text could be scrolled across the screen, reporting volume build-ups and average traveling times. At a more complex level, an integrated system could be used to display maps with color codes for levels of congestion, scroll text describing average time and speed, transmit video of actual roadways, and allow user interaction with the system. Currently, no such integrated system exists.

Within the United States, Teletext in television has been exclusively provided by Zenith Corporation. However, in the near future both Panasonic and Sony plan to offer teletext capability with their television sets. This medium of information delivery has already been successfully employed within the United States for close captioned programs.

Until recently, screen display of traffic information had been thought of primarily in terms of providing motorists with pre-trip, route planning information. Now, consideration is being given not only to providing terminals at strategic points in the highway system, permitting the user to update information while en route, but also to providing in-car terminals that provide route guidance in response to changing conditions while drivers are on the road.

The remainder of this section discusses topics relating to pre-trip information in greater detail by examining existing and potential delivery systems. The discussion covers implementation for drivers, as well as for traffic systems management centers, and includes adaptations of weather reporting methodology.

Graphics and Teletext for Drivers: Locally, Kirkemo (Kirkemo, 1987) studied the feasibility of implementing a graphic display system to deliver traffic information to drivers in the Puget Sound region via local access cable TV. The potential impact on drivers' commuting behavior as well as potential benefits resulting from changes in commuting behavior were also analyzed. Kirkemo proposes both a cable only and a cable/microwave option, and examines the costs and benefits associated with each option.

Kirkemo used computer simulation, putting a graphic map with text messages at the bottom of the television screen. Such a system was shown to have potential for reducing traffic delays. The necessary hardware for screen generation is in place, and cost effective methods to provide the transmissions to the cable companies exist. The report concluded that "individual [transportation system management strategies] may only have a marginal impact on the ability of the system to deliver an acceptable level of service. The development of a number of coordinated programs could have a synergistic impact" (Kirkemo, 1987, p. 58). The evaluation of graphic display options proceeds with that goal in mind.

For the past year in Seattle, Metro Traffic Control, a traffic information company based in Houston, Texas, has been operating a traffic reporting service. In conjunction with KIRO-TV, Metro Traffic Control will expand their services to television with their proprietary system, TELETRAC, late in the summer of 1988. TELETRAC uses a graphic map display of the local freeways and features a reporter giving a vocal traffic report at the same time. The station will display a map provided on a video disc by TELETRAC. The traffic reporter, based at the Columbia Center, will report live to the station over a high quality telephone line from information obtained from both eye-in-the-sky reporters and ground-based vehicles. Initially, the station will give three reports during the afternoon rush-hour news shows; expansion will be based on public reception (Perry, 1988).

A TELETRAC-type system is used in Houston and elsewhere in the country but is only a partial solution to the pre-trip information problem. While this type of system does provide a picture of traffic problems that is easily understood, it is basically static, has little potential for interaction, and is not based on individual users' needs. In fact, the display is simply a picture of the relevant section of the traffic system with a voice report and an arrow which points at the particular trouble spot being described. The system's best use will probably be as a bridge between current Puget Sound traffic information systems and the more dynamic, interactive, user-based information system the region needs in the future.

Beyond the local area, teletext will be tested in connection with the Smart Street project in Los Angeles, beginning October 1988. A teletext traffic message will be broadcast either by satellite or by local television stations to homes within a suburb of Los Angeles. The effect of the broadcast upon the commuting public will be determined by a survey.

Another southern California traffic reporting service, called MONICA, is operated by the Automobile Club of Southern California in San Diego. This teletext service, one of the best currently in operation, includes graphic display of current traffic information that is provided to local televisions stations and used in morning and evening news slots. The screen consists both of a map of the local freeways and text lines at the bottom which give the current average speeds for each highway. The map is color coded to show how traffic is flowing and where trouble spots are located.

The information in MONICA is downloaded by the Auto Club every thirty seconds from CALTRANS mainframes to a microcomputer . The Auto Club must then enter by hand the information to update the color codes and time averages. The time lag from occurrence to television report is 2 to 5 minutes.

The color coded map and bottom line text reinforce each other. The text provides viewers with specific information about particular arteries; the color coding provides viewers with general system information they can understand quickly and easily. The code uses green to represent a traffic flow of 40 mph and above, yellow for 20 to 40 mph, and red for 0 to 20 mph. Although this system is dynamic and changes with new information, the end user still has no control over the content or display of information (Taylor, 1988).

On the international level, two examples of teletext systems are CEEFAX in Great Britain and ANTIOPE in France. ANTIOPE's service includes a map display of conditions on major roads.

Televised Graphic Display of Weather Information: There is considerable untapped potential for televised display of real-time traffic information, probably because this is still a relatively new field. There is, however, much to be learned from efforts in related fields to provide dynamic, graphic information to the public. Television weather graphics, for example, are more sophisticated and have a longer history than televised traffic information, and may provide some insight for future traffic displays. Over the past forty years, television has successfully brought the complex science of meteorology to the general public in a text/graphic format that is easily understood. People now use this information in planning their daily activities. There is no reason why the same cannot be accomplished with traffic information.

Television weather reports have changed greatly from the first hand-drawn weather map displayed in the United Kingdom in 1936. Today, satellites beam accurate pictures to earth every few hours; those pictures are compiled and displayed in sequence, like a short movie, to show weather pattern changes over a quarter of the earth's surface. In addition, system operators have control of the display options, including cloud pattern sequences, charts with friendly icons, and weather statistics. This evolution from a static, non-interactive, one-dimensional system to a dynamic, interactive, multi-dimensional system provides the base for today's rapidly evolving technology, and provides a possible model for future developments in the graphic display of traffic information.

As weather reporting has changed, so has the public's perceptions and expectations. The main users of early weather graphics were forecasters, aviators, and sailors. These users needed detailed and accurate information; thus, the early graphics included much numerical data. As television technology improved and television use spread, televised weather reports switched from expert audiences to the general public, and the graphic images changed to respond to the needs of these new viewers. The data gave way to simple one or two word descriptions and easily understood symbols. General descriptions replaced details because the public was more interested in deciding how comfortable their day would be rather than in what the cloud patterns and wind directions would be.

Major changes are once again occurring; the driving forces again are technology, and the public's perceptions and needs. The latest computer technology allows for real-time display of information in many forms. In addition, communication technology is moving from a focus on massive audiences towards smaller, specific audiences. At the same time, the public is demanding information tailored to such specific users as agricultural, recreational, and travel groups. Because computer technology allows the information to be shaped to specific uses, this customization can work successfully. These new changes are built on the visual literacy currently held by the general public, and can therefore be easily initiated.

Several problems with televised weather information relate to televised traffic information. One common problem is the tendency in both areas to overwhelm the public with information. The World Meteorological Organization (WMO) reports that ". . . the amount of information that can be recalled from a weather forecast by the recipient is independent of the length of the message. Therefore, no matter how much information is presented by the forecaster, there is a limit beyond which no additional information can be assimilated" (WMO, 1987, p. 25). WMO also reports that the public is likely to remember certain items more than others. The public's ability to absorb and distinguish information must be considered in the design and implementation of the graphic system used.

Another common issue is the competition for television news time. Television time is a valuable commodity that is allotted carefully. Consequently, weather reports have become very concise yet very vivid and even entertaining. They make use of verbal and visual means of transmitting information at the same time. Traffic reports do not yet meet the same standards.

Beyond these general problems, both areas must do further work to study the requirements of end users and to design displays that take these requirements into account. The World Meteorological Organization has recommended the following presentation design guidelines. These ten common sense recommendations are as applicable to delivery of traffic information as they are to weather reporting:

- Understand the needs of users.
- Tailor (broadcasts) to meet the users' needs.
- Select the proper medium to reach the users.
- Use language familiar to the users.
- Resist the temptation to add information the users do not need.
- Stress that advanced technology is being used in observation, prediction, or communication whenever possible.
- Use graphic presentations when possible.

- Present information with enthusiasm and good humor.
- Encourage user response to (broadcasts).
- Modify presentations as indicated by users' reactions.

Graphics and Teletext for the Traffic Systems Management Center: The previous discussion focused on the use of graphics and teletext to present information directly to the general public. Various transportation and traffic centers are also using teletext and graphic systems to manage freeways and to provide information to traffic specialists who in turn pass this information on to the media for public use. The Seattle area Traffic Systems Management Center is one example of such a system.

From Seattle's Traffic Systems Management Center, WSDOT operates the Surveillance, Control and Driver Information System as part of its overall FLOW system. The Surveillance, Control and Driver Information System combines radio communication, electronic metering, computer generated graphic displays, and closed circuit television to gather a real-time picture of the Seattle freeway traffic situation. This information is then passed on to local media for broadcast. Presently, radio and television traffic reporters call in to receive a detailed report from WSDOT system operators.

Since the current dissemination of information depends on phone conversations between expert intermediaries and local media and then on subsequent radio or TV reports, the system is neither as timely or as responsive to driver needs as might be desired. There is, however, considerable potential for more technologically sophisticated and user oriented transmissions of this real-time traffic information.

Two subsets of the Surveillance, Control and Driver Information System offer options for presenting information more directly and interactively to the commuting public: the computer-based Graphic Display System and the Closed Circuit Television (CCTV) system.

Graphic Display System

The Graphic Display System presents a graphic representation of traffic on the freeway system in the Seattle area, including I-5, I-90, I-405, and SR 520. Traffic is monitored by strategically placed loop counter stations which transmit their data to a mainframe computer. From this data, the computer generates a color coded map of the freeways. The level of congestion per mile is depicted by the color of the roadway section; green indicates no congestion (occupancy 0-15%), yellow indicates the onset of some congestion (occupancy 15-22%), red indicates moderate congestion (occupancy 22-35%), and flashing red indicates severe congestion (occupancy above 35%).

In addition to the color coded display of the entire freeway system, two additional displays are available. The first illustrates conditions within any given one-mile section. The location of each loop counter station is shown graphically within the one-mile section and the congestion level at each station is depicted using the color codes stated above. The volumes and occupancy values per minute are shown for each station, as well as volumes per minute on all on and off ramps within the one-mile section. Finally, a second display shows the operation on any one ramp in the system. The metering rate and mode are shown numerically, and the status of the ramp signal in real time is depicted, as well as the occupied/not occupied status of all on-ramp loops.

The information retrieved from the screen is used in at least two ways. As previously mentioned, information is passed on to traffic reporters who in turn pass it on to the public. In addition, operators are able to monitor components of the Electronic Surveillance and Ramp Metering subsystems to determine equipment performance. Operators do this monitoring by comparing the road conditions reported on the display screen with other sources (CCTV, patrol vehicles, time of day) to verify that the reports received are correct. If operators suspect a malfunction or a discrepancy, they can display, on a separate computer terminal, the section or station involved to examine the data more closely. If a problem is discovered, specific information about the road station as well as system information is available to help correct the problem.

As an example of this maintenance function of the system, suppose that the graphic display shows a one-mile section of I-5 severely congested (blinking red),while all other sections around it indicate no congestion (green). The time is 9:20 A.M.--after rush hour. The operator can check the section via CCTV if it is in the range, or check the log of calls from the highway patrol to see if an accident condition exists. If neither of these sources provide any information, the operator can check the status of the loop indicator for the one mile section. This check might reveal that the only station in this section currently functioning is the one displaying 99% occupancy. The operator could then switch the display to that particular station and might discover a stalled vehicle on one station creating false readings. Having confirmed that no general traffic congestion exists, the operator could refer the problem section to a maintenance crew.

Closed Circuit Television System

The Closed Circuit Television System (CCTV) is used primarily for incident verification and for reporting traffic conditions to commercial radio stations. Presently, 26 camera stations cover the freeways listed earlier. As of early June 1988, ten were functional, covering both I-5 from the Kingdome north to Northgate and the Mercer Island floating bridge.

The CCTV System is composed of three components: the cameras, the touch screen control, and the program monitors. The cameras are mounted throughout the system on utility poles and are connected to the main system by coaxial cables (I-5) or microwave (I-90). The touch screen control allows the operators to interact and control the entire system from one location. The screen includes a freeway map showing all camera locations, a program monitor section, and a camera movement control section. The two program monitors display the video selected from the control screen. The monitors can be programmed to display different camera views in a sequence that allows the operators to monitor the traffic without continually changing camera selections.

The Camera Control Center makes the system unique. All cameras are controlled by a microcomputer through a touch screen system that features a graphic interface similar to the Graphic Display System. Operators need only touch the screen area that they wish to operate and the controls for that instrument are activated.

Three problems surfaced when this system was observed in action. First, the video monitor for the graphic display is a standard television monitor and the resolution of the image is marginal; the resolution would not meet existing standards for televising the information directly to the public. Second, the human-machine interface is clumsy. A trained technician is needed to operate the system, and the control is designed in a way that makes no intuitive sense. Before this system could be used for direct delivery via personal computer (see next section), the interface would have to be changed. Finally, the touch screen technology controlling the CCTV system malfunctions intermittently, interrupting operation of the system.

Ideally, the Graphic Display and the CCTV systems would be integrated, placing them under one easily operated control. What is currently in place is adequate for current uses, but this integration would give the system an added dimension that would enhance its ability to serve the general public, either as a source for displaying traffic information on network or cable television, or delivered directly via home or office computers.

Micro-Computers: Since visual traffic information like that presented in the Graphic Display is computer based, microcomputers connected via modems to traffic information systems are an exciting future possibility for transmitting traffic information directly to drivers. This option would allow individual interaction with the information system, allowing drivers to tailor the information to personal needs. Appropriate microcomputers already exist in growing numbers in homes and offices, and are likely to become a standard option in cars of the future. Most small computers can display graphics and text, though video reception is an expensive option that probably is not viable at this point in time.

It is difficult to gauge the present practicality of this kind of system since no real-time motorist information system in this country currently uses microcomputers at the receiving end. Therefore, it is worthwhile considering microcomputer applications that use interactive graphics in other transportation areas. Microcomputers have been connected through modems to information services in such areas as vehicle route scheduling and transportation planning. There are several products, in the United States and internationally, with a range of interactive capabilities available in each field.

United States Systems: Vehicle routing software is used to plan trips for fleets of vehicles to make the best use of time and distance (Klien, 1987). Using a map display, the operator can key-in starting locations, delivery points, and pick up sites for back hauling. The software then compiles the information and displays a route to use. The best systems allow "what-if" manipulations to test new conditions. They also make use of such variables as natural barriers, speed zones, and travel standards.

A motorist information system could use these characteristics and plug in real-time congestion information to complete the system. Of the packages available, Roadshow from Routing Technology Software, Inc., offers all of these capabilities plus "geocoding." Geocoding is "a computer based routing method that matches an address with specific map latitude/longitude coordinates. . . It allows for natural barriers and travel over streets/highways, calculating true distances, not straight line distances" (Klien, 1987, p. 12). This feature is essential for a system designed with the general public as the end user.

There are several packages in transportation planning that have features desirable for traffic reporting (U.S.D.O.T., 1987). NEDS from the Center for Urban Analysis uses zooming capabilities to work with a whole network or just part of one. Quick Response Systems II from AJH Associates allows for importing data defined for other applications. This feature is useful for working with existing technology. CARS from Rodger Creighton Associates displays simulations of traffic flows. This simulation suggests the use of simple animations for displaying congestion problems. MicroTRIPS from MVA Systematica displays volumes of traffic by varying the bandwidth of the road. This simple component is a powerful visual attribute. In addition to all of these individual features, Horowitz and Pithavidian (1987) state that the best systems relate map display to the real roadway systems in a fashion that is easily understood. Using highway identification symbols would be an appropriate example of this relationship for a traffic information display.

International Systems: Interactive Videotext, exemplified by TELETEL-ROUTE in France, ROUTE-TEL in Great Britain, and ARCS in Australia, requires a remote terminal and a phone connection. Subscribers have access to a huge data-base of intersections and road segments, and to computer algorithms capable of calculating the quickest, shortest, or cheapest route from one point to another. Videotext output takes the form of a series of directions similar to what you would give a friend you were directing to your house.

One current disadvantage of videotext is the difficulty in updating the data-base in response to changing road conditions. However, the current system can be adjusted for extended conditions, such as ongoing construction, and current research is aimed toward developing updating capability.

Route Tel System developed by TRRL in the United Kingdom provides customized routing information to the user via mainframe terminal. The system is currently used to provide route information; application of a real-time traffic information system would be an extension. The cost of such systems is prohibitively high, but, with declining computing costs and the growing computing power of microcomputers, solutions like these will become more feasible in the future.

Telephone: Perhaps because it is such a common communication medium, telephones are rarely considered as a means of delivering real-time traffic information. However, special telephone numbers within the Seattle metropolitan area already provide timely information to the inhabitants, though this information is only marginally traffic-related. These messages are either pre-recorded or interactive in nature. Interactive phone messages require the user to punch numeric codes on a touch-tone telephone to retrieve specific information. Systems that exist today provide information on weather, sports, or the stock market. The most relevant service is a comprehensive telephone information system which SEA-TAC Airport has implemented to provide parking and flight information. Oracle Communications, the supplier of SEA-TAC's system, has discussed with WSDOT their plan for supplying Seattle drivers with interactive, real-time traffic information via telephone.

Similarly, a state-of-the-art, phone-based trip planning system is being developed by the Media Lab at Massachusetts Institute of Technology (Davis, 1987). The system, called Direction Assistance, uses techniques from artificial intelligence and natural language processing. Direction Assistance will provide information to assist travel within the Boston area. The project translates 11 square miles of the Boston area into a program that communicates with naive users over the telephone through a natural language interface. The transmission of information has been divided into three categories: obtaining the driver's origination and destination, finding the direct route, and describing the suggested route in such a manner that the user is able to obtain the information necessary to reach the destination. The system does not, however, provide traffic information other than route guidance.

The literature does not indicate that a system similar to Direction Assistance has yet been developed to provide real-time traffic information. However, such a system is feasible and, with an increased number of cars with cellular phones, could help alleviate traffic problems by providing not only pre-trip information, but en route information as well.

Motorist Information Systems: En Route Information for Motorists

In addition to information received before trips are begun, motorists need information about traffic on their route while they are traveling. This tactical information should enable drivers to (a) make effective route choices, (b) travel routes with which they are previously unfamiliar, and (c) respond quickly and appropriately to unforeseen incidents that occur en route. The means of conveying tactical traffic information to drivers en route can be divided into two categories: information delivered outside the vehicle and information delivered inside the vehicle. Information delivered outside the vehicle is visual and is delivered by various types of traffic signs. Information delivered inside the vehicle may be visual, delivered by an in-vehicle navigation system, or it may be verbal, delivered by commercial or dedicated radio, or by cellular telephone. The following subsections of this report examine all of these systems.

Visual Information Outside the Vehicle: Information delivered to motorists outside their vehicles is communicated by means of visual signs. Static signs have been most commonly used for various traffic control, route guidance, and diversionary purposes. Variable Message Signs (VMS) are newer, and are capable of being electronically adjusted to inform motorists of prevailing conditions. VMS can convey real-time traffic information to drivers, enabling them to make appropriate decisions at key decision points during their trip.

A well designed sign system should ensure that all the information the signs convey can be read and understood by motorists within the time period that they view the sign. In addition, motorists must be willing and able to respond to the sign while the appropriate response is still possible. Since most of a driver's stimulus input is visual, an understanding of the visual abilities of drivers is essential in the design and placement of effective traffic signs.

One of the characteristics which influence the perception of signs, be they roadway or VMS, is a personality characteristic referred to as field-dependence/field-independence. Basically, field-dependent people are better than are field-dependent people at distinguishing relevant from irrelevant cues in their environment. Various psychometric tests measure field dependence. Goodenough (1976) has reviewed the literature on these tests and has summarized several experiments and field studies in the area as follows: as compared to field-independent drivers, field-dependent drivers are slower to recognize developing hazards and to respond to embedded road signs (those surrounded by other stimuli), have greater difficulty in learning to control a skidding vehicle, and are more likely to fail to drive defensively in high-speed traffic. Other evidence (Shinar et al., 1983), indicates a relationship between field-dependence and eye movement behavior. Thus more field-dependent drivers have longer eye-fixation duration and therefore take longer to pick out relevant information.

These results indicate that personality or perceptual styles of drivers, such as field-dependence, are important variables to consider in the design of motorist information systems and in the design of surveys which desire to isolate these groups in the sample population. To clarify the factors involved in the design and placement of effective signs, the following subsections include further review of recent relevant human factors research.

<u>Effectiveness of Sign Content</u>: A study on the effect of freeway diversionary sign content and motorist behavior found that, despite instructions to exit the freeway, one-third of 360 subjects continued on the freeway (Mast and Ballas, 1976). The severity of the message had a direct effect on the number of people choosing an alternate route. A message in the imperative mood had the greatest influence; signs that explicitly stated a message such as "USE I-XX BYPASS NEXT EXIT" were interpreted as commands. The same study also concluded that motorists prefer time-delay information over incident information. A Finnish study found that as motorist's motivation increased, their reaction time when faced with highway signs decreased (Summala and Hietamaki,

1984). These and other findings indicate that the content of diversionary signs should be tied to a motorist's motivation for choosing an alternate route.

Other studies have found that age has a significant impact on recall of sign content, with younger drivers recalling the signs better than older drivers (Milosevic and Gajic, 1986; Evans and Ginsburg, 1985). With the average age of the driving population increasing, an attempt will have to be made to determine the appropriate message content and its effect on various age segments of the population.

A fair amount of controversy exists on the relationship between recall of signs and professional status of the driver. Milosevic and Gajic (1986) found that the professional status of the motorist does affect the recall of signs; professional drivers have higher recall than non-professional drivers. In contrast, Hakkinen (1965) found that non-professional motorists had better recall of signs than professional motorists. To further complicate matters, Johannson and Rumar (1966) found that professional status had no effect on recall of signs. These studies were all performed in different countries; Milosevic and Gajic's study was performed in Yugoslavia, the Hakkinen study was done in Finland, and Johannson and Rumar's study was done in Sweden. Perhaps the geographic location of the study affected the results. In any case, further research is needed to gauge the effects of different driver types on the recall of signs.

A study to measure the effect of "close following" signs was done at the Transportation and Road Research Laboratory (TRRL) in England (Helliar-Symons and Ray, 1986). Its purpose was to measure the effectiveness of warning signs on the behavior of motorists on major motorways. Findings indicated that females responded to signs more than males. The study also revealed that the response to signs increased with age. The same study also concluded that drivers of passenger cars responded more to signs than drivers of heavy or light goods vehicles. Generally, in the TRRL study, professional drivers responded less to the signs than non-professional drivers.

Research examining methods of conveying the content of traffic signs agrees that symbolic sign messages have a number of advantages over word sign messages. Symbolic sign messages are identifiable at greater distances and are more legible at a quick glance than are verbal messages (Elks and Dower, 1979; Whitaker and Stacey, 1981; King, 1985). The meaning of symbolic traffic signs is generally understood more quickly than that of the corresponding signs with verbal messages. Furthermore, symbolic messages can be recognized more easily under degraded conditions, such as rain, fog, or snow (Ells and Dewar, 1981).

These studies only begin to address the many questions about message content that must be answered before a truly effective motorist sign system can be developed.

Sign Placement: According to Mourant and Rockwell (Mourant and Rockwell, 1970), peripheral vision is used for monitoring lane position, other vehicles, and road signs so that the eye's center of focus may be directed where a clearer examination is needed. Since peripheral vision, with its poor visual acuity, is used to monitor the road edge, easily detected lines and conspicuous road signs are particularly important. In freeway driving, the search and scan pattern of drivers becomes more compact; as drivers become more familiar with their route the center of the pattern shifts down and to the left. The center of the final visual scan pattern is located above the right road edge marker and slightly higher than the horizon (Mourant and Rockwell, 1976). This pattern indicates that traffic and road signs should be placed on the right side of the road (in the direction of travel) and should have the sign board at an elevation slightly higher than the horizon.

On curved roads the visual fixation patterns of drivers follows the road geometry, whereas on straight roads the search behavior is less active; most of the fixations are close to the point, straight ahead of the driver, where objects appear stationary in the moving visual field. In driving through curves, drivers direct their eye's center of focus to lateral placement cues rather than relying on peripheral vision (McDowell and Rockwell, 1977). The process of curve scanning begins in the section of road prior to the curve itself. Search and scan patterns on right and left curves are not symmetrical: eye movements to the right on right curves are greater than eye movements to the left on left curves. The studies on curves suggest that the optimal placement for advisory curve signs may be just prior to the section of road before the curve, so that drivers are warned to switch their visual search strategy and maximize their curve scanning time prior to entering the curve. This placement is especially critical for roads designed for high speeds.

Eye fixation patterns also differ when drivers travel at different speeds. Drivers looked further ahead when traveling at high speed (80 km/hr. or more). As driving stress (rated subjectively) increases, the frequency of short eye fixations increases, the frequency of long fixations decreases, and eye movement distances become shorter (Whalen et al., 1977).

Sign Visibility: Conspicuity is the property that causes an object to attract attention or to be readily located by search. A study by Cole and Hughes (1984) concluded that the angle of eccentricity of an object (deviation from the stationary point in the driver's straight-ahead field of vision) to the observers line of sight is an important factor in determining conspicuity. This finding implies that, to achieve conspicuity, traffic signs should be located so that the sign has a small eccentricity to the observer's line of sight. Small angles of eccentricity are afforded by minimizing the distance the sign is set off to the side, and by ensuring a long observation distance. A larger sign at a greater angle of eccentricity is not as effective as a smaller sign at a lesser angle. The study found that conspicuity was not strongly dependent on either the object's size or the amount of light the object reflects. This conclusion contradicts the results of an earlier study conducted by Cole and Jenkins (Australian Road Research, 1982) which found that size is an important determinant of conspicuity.

Age has been related to the visual perception of traffic signs (Sturgis and Osgood, 1982). Visual acuity decreases significantly with both increasing age and decreasing background luminance (luminance is the amount of light leaving a surface, whether reflected or emitted). Threshold target luminance increases significantly with age. Glare has a multiplicative effect on threshold target luminance that is independent of age. Older persons (on the average) do have significantly greater target luminance requirements in the presence and absence of glare. A similar study carried out by Evans and Ginsburg (1985) supports these findings.

Visual tracking of a sign is affected considerably when the vertical distance between signs in an array was 18 degrees of visual angle or greater (Noble and Sanders, 1980). This study also found that tracking is best when color provided a perfect cue. These findings indicate that highly distinctive colors should be used for signs. In addition, symbolic cuing lightens the cognitive load in a divided attention context (Chechile and Sadoski, 1983); verbal cuing did not reduce the cognitive load, since it still requires attention to read the verbal message. Together, these studies suggest that traffic signs should have highly distinctive background colors, coupled with symbolic messages that minimize the human information processing task. The optimal design would incorporate high conspicuity and contain a message that is legible and understandable.

Under conditions of degraded visibility (fog, heavy rain, and darkness), the overall degradation in visibility does not lower the drivers perception of all driving-related cues. Rather, it shifts the driver's attention towards warning signs that contain the preview information that is not directly visible in their view of the road ahead (Shinar and Drory, 1983). Shinar and Drory also found that at night, when the view of the road ahead is severely restricted, drivers' recall of signs is higher than during the day, when drivers can obtain most of their information directly from the view of the road ahead. Olson and Bernstein (1979) found that in darkness, more highly reflective sign backgrounds create better legibility at greater distances. This study also concluded that reflective backgrounds reduce the adverse effects of degraded viewing conditions. Luminance contrast requirements were found to be lowest for highly reflective backgrounds and increase as background reflectivity increased.

The greater Seattle area is known for its rainy conditions. Unfortunately, there have been few studies of the legibility of highway signs and the visual load they demand in rainy situations. A study by Bhise, Meldrum, Forbes, Rockwell, and McDowell (1981) concluded that diver's visual acuity, including the ability to read signs and to see at a distance, decreases with increasing rain intensity. More study and research in this area needs to be done to understand the factors involved in traffic sign design to accommodate the effects of darkness and rain.

Overall, human factors considerations are a crucial component in the content, placement, and design of highway signs. Considerable research is yet to be done, particularly on the human factors issues related to VMS and other new sign technologies.

In-Vehicle Navigation Systems: With the reduced cost, increased compactness, and improved capabilities of sophisticated communication equipment, externally linked route guidance has become a topic of interest among traffic planners. In its most sophisticated form, this guidance consists of an in-vehicle navigation system that communicates with transmitters and receivers along the roadway or on satellites, providing the motorist with information about location, alternate routes, best route to destination, existing road conditions, and other vehicles.

United States Systems: ETAK Inc. has developed an online navigational display system for automobiles. The ETAK Navigator consists of a Cathode Ray Tube (CRT) display screen located on the vehicles dashboard. The display is a map similar to the screens discussed in previous sections on television and microcomputers, with one primary difference: instead of a large overview of a freeway system, the system offers a point-of-view map geared toward the destination of the driver (Honey and Zavoli, 1986). The direction the car is traveling always faces the top of the screen; the display rotates to accommodate any change. The map gives the driver the advantage of knowing what route options are available from the car's current position.

An on-line navigational display system, using ETAK, is currently being tested in the Los Angeles area as part of the traffic management system called Smart Streets. A three year research project, called Pathfinder, is testing the feasibility of electronically linking traffic condition information for in-vehicle navigation systems. The project, conducted by CALTRANS, uses 25 specially equipped cars donated by GM. Each car has an electronic map of Los Angeles streets displayed on a console screen fitted to the dashboard. During the project, the system will be refined to receive real-time traffic and accident information from CALTRANS' traffic operation center. The users of the four inch ETAK computer screen will program in their present location and destination and select one of eight different scale sizes in which to view the map. The selections will be transmitted and received over FM radio or cellular phone. The central computer will transmit graphic or textual traffic information on the screen. The visual information will be complemented by audio transmissions. Preliminary results from this study are expected by mid 1991.

International Systems: Internationally, a number of approaches to in-vehicle route guidance systems have been studied. As early as the 1960s an American system, Electronic Route Guidance System (ERGS), was tested. ERGS linked automobile and information units on the roadway by radio. A West German System, ALI (Destination Guidance System), gathered information from induction loops in the road and recommended optimum routes to individual motorists. Both of these projects were discontinued because of the prohibitive cost of modifying the roadway.

Currently, a number of intermediate route guidance systems are being developed. The CARIN system from the Netherlands provides a prototype digital map on which the motorist and the proposed route can be located. An in-vehicle computer then keeps track of the vehicle's direction and speed, and gives a dead reckoning location of the vehicle. The ROESY system from Great Britain takes an innovative approach, allowing the motorist to create a digital map of only relevant roads and intersections. The computer then uses that map to plot an optimum route. Cost is still high for any version of this technology: an in-vehicle CARIN system would cost approximately $1300. As systems are refined and production volume increases, costs are expected to drop and the capability of the systems is expected to increase.

Effectiveness of In-Vehicle Navigation Systems: A navigational display in an automobile poses a unique set of human behavior problems. Virginia Polytechnic Institute has completed a series of human factor studies to evaluate the use of an in-vehicle navigational system for route guidance (Dingus, Antin, Hulse, and Wierwille, 1986; Wierwille, Hulse, Fischer, and Dingus, 1987). These studies, using the ETAK Navigator described earlier, found that ETAK is as effective a means of route guidance as road maps; the difference in performance between the two was found to be statistically insignificant. The dependent measures included eye scanning and dwell time, task completion, and quality of driving.

The automotive industry has already incorporated various forms of electronic displays in automobiles. Ford Motor Company has funded extensive research on electronic and digital displays, and concluded that subjects using digital displays of numeric information such as vehicle speed could more accurately determine actual speed than subjects using dials or meters. However, 38% of the 100 subjects found digital displays to be the very distracting (Baines and Simmonds, 1980).

An alternative to CRT or digital displays is the Heads Up Display (HUD) used in aircraft. In a HUD, information is presented to the user by displaying altitude and pitch information on the windshield. Thus the display information is superimposed on the real world view, enabling a user to scan the forward view without loss of information. (Harding, 1980). Nissan Motor Company will be introducing a HUD in its latest automobile models to provide information that has previously been conventionally displayed on the dashboard.

Human Factors Issues for In-Vehicle Navigation: When people are required to do more than one task at the same time, referred to as divided attention or timesharing, performance on at least one of the tasks usually declines. The driving task requires timesharing; the driver has to respond to visual stimuli while using motor skills to control the vehicle. For the driver, controlling the vehicle is the primary task. Studies have been conducted to determine how driving affects performance on a secondary task such as reading randomized digits from a digital counter mounted above the console (Wierwille and Gutmann, 1978).

Performance on single and multiple tasks, such as operating navigational instruments while driving, has been found to be related to personality type. For example, type A personalities who are competitive, achievement oriented, and have an extreme sense of time urgency, perform better when doing two tasks simultaneously (Damos, 1986). In addition to personality, there is a strong correlation between self-assessed and objective measures of navigational capabilities (Streeter and Vitello, 1986).

Human factors specialists are examining the design of the CRT displays used in the 1986 Buick Rivera (Zwahlen, Adams, and DeBald, 1987). Traditional knobs make use of motorists' tactile senses, whereas the CRT type panels require the driver to visually scan the instrument. By measuring lane drift, the study concluded that operating a CRT type apparatus is detrimental to driving. In a related study, Noy (1987) found a direct correlation between the complexity of the visual task and poor driving quality. This correlation is attributed to the heavier cognitive load that drivers experience while performing the visual task. These findings suggest that in-vehicle navigation and route guidance systems require further research before implementation.

Studies done at Virginia Polytechnic Institute also concluded that navigational systems demand more attention than common road maps (Dingus, Antin, Hulse, and Wierwille 1986; Wierwille, Hulse, Fischer, Dingus, 1987). The 1986 study compared the attention required to read a speedometer (low attentional demand) or tune a radio (high attentional demand) to the attention required to navigate using a display or a map. The 1987 study investigated the adaptability of users' visual scan patterns. The experiment involved two kinds of changes in the visual scene: changes the drivers anticipated (advance notification, e.g., driving down a winding road), and changes the drivers did not anticipate (no advance notification, e.g., an oncoming vehicle turning left). The studies concluded that motorists can, and do, adapt to new technology in vehicles and to information overload. Although motorists do adapt, the researchers caution designers to work on reducing the attentional demands of the navigational instruments.

The following design rules for CRT displays in vehicles have been suggested by various human factors specialists (Zwahlen et al., 1987; Streeter and Vitello 1986):

• A maximum of 3 consecutive looks should be required to operate a CRT touch panel control system.

• The acceptable time range for interrupting the driver's scanning of the road to operate a CRT panel is 2 to 4 seconds (although we recommend much shorter ranges).

• HUD (Heads up Display), used in fighter aircraft to display information directly on the windshield, may be an alternate method for displaying information.

• The placement of the navigational instrument display should maximize the driver's use of near peripheral vision, so that driving tasks may be performed while attending to the instrument.

• Although computer generated pictures are effective and can be transmitted to an in-vehicle computer, navigational information should be presented vocally.

This last point brings us to an alternative or adjunct to in-vehicle displays--in-vehicle voice instructions.

In-Vehicle Voice Instructions: Primarily through radio broadcasts, voice instructions are an effective means of transmitting traffic information to motorists, and their application could be significantly extended. Research funded by the federal government has concentrated on the aircraft environment; however, the general principles are applicable to automobiles. Some research has indicated that voice warning systems result in quicker response than tonal or visual displays, particularly in high stress situations.

Developments in radio broadcasting are aimed at solving two fundamental problems: first, delivering to the individual motorist the information needed to follow a specific route, and second, immediately informing motorists of an incident or a change of conditions. There are currently two modes of transmitting audio information to the motorist: a multi-purpose system, designed to meet many needs, including the delivery of necessary traffic information (i.e., commercial radio); or a dedicated system designed for traffic information only. The following subsections will examine both modes.

Commercial Radio: One of the most widely used means of transmitting traffic information is through commercial radio stations. There are several radio stations within the Puget Sound area that attempt to broadcast up-to-the-minute traffic information, using either information from the DOT center or information from their own traffic reporters, often in helicopters. The service is often inefficient: the information may be delayed, may not be broadcast when needed, may not be heard when broadcast, and, when heard, may be irrelevant to an individual driver's journey. Some of these problems are addressed by dedicated radio systems.

Dedicated Radio Systems: Dedicated audio instruction systems can provide 24 hour, up-to-the-minute traffic information and route guidance to automobiles in transit. ARI, "motorist's broadcast information," the West German system developed by Blaupunkt, has met with some success and acceptance from motorists. ARI is made up of over 40 broadcasting stations separated into 12 zones. The broadcast signal is modulated in such a way that stations within zones can be distinguished; another special modulation indicates when a station is broadcasting.

The ARI system requires a special receiver capable of interpreting these modulations; these receivers come in various levels of sophistication. The simplest and least expensive ($15 to $30) informs the motorist with an indicator light, when the radio is tuned to the local information station. The top-of-the-line receiver (cost unavailable) automatically detects the broadcast, tunes the radio to the appropriate information station, and either plays or stores the message, at the motorist's discretion.

ARI is currently in operation, and an estimated 80% of West German motorists have some form of ARI receiver. Other systems are in experimental and prototype stages. For example CARFAX, an English system not yet implemented, depends on transmitters rather than receivers to prevent interference. A computer operated system would inhibit transmitters in the same range from broadcasting at the same time. A receiver for this system costs the motorist approximately the same as the cheapest ARI receiver. CARFAX is currently being delayed by a lack of available, appropriate broadcast frequencies.

Radio Data System (RDS) avoids the broadcast frequency problem by piggybacking a digital code onto a standard FM signal. Again, the motorist must have a special receiver and decoder. One of the strongest features of RDS is that the digital signal can be interpreted into any language, verbal or symbolic. In addition, the message can be easily stored in its digital form and called up at the motorist's convenience.

Traffic Incident Information System (TIIS) in Japan has a different design; the TIIS transmission overrides any other broadcast. The special receiver for this system automatically tunes to TIIS whenever TIIS is transmitting. If the driver does not wish to hear the message, he or she can manually tune the radio to another station.

Highway Advisory Radio (HAR) is already in place in many parts of the United States. HAR is relatively unsophisticated. By flashing lights on a highway sign, it signals motorists that a short-range, dedicated radio station is currently broadcasting potentially useful information . The motorist must then manually find the station while driving. Generally, HAR is not used for real-time traffic reports. Despite its current lack of technical sophistication, HAR might serve as the infrastructure for a more advanced system.

Effectiveness Of Voice Instructions: If dedicated voice systems are to be truly effective in the future, as much attention must be paid to the effectiveness of this media, as well as to other human factors issues related to voice commands and instructions, as is currently being paid to technological issues of transmission and reception.

A New Jersey study compared the effectiveness of route information disbursed by two media: audio tape instructions and maps (Streeter, Vitello, and Wonsiewicz, 1985). Subjects given the audio information performed better (drove fewer miles) than subjects given maps. In addition, the map group made 67% more errors than the tape group.

A survey conducted in 1971 by the Texas Transportation Institute (Dudek et al., 1971a) revealed that 62% of the survey participants could benefit from radio reports. The same survey revealed that, among the 4 modes of communication (radio, signs, tv and telephone), radio was the most preferred mode.

Additional Human Factors Research: Traditionally, auditory information within automobiles has taken the form of buzzers and bells. However, recent developments in computer and speech technology have resulted in incorporating synthesized or natural voices for such purposes as warning messages about using seat belts or leaving headlights on. Public acceptance of such messages has been mixed. The success of "talking products" for traffic information, including natural or synthesized voices, will depend upon the application of human factors principles.

The following general issues have been cited as crucial in the design of audio message systems (Michaelis, 1980; Schwab, Nusbaum, and Pisoni, 1985):

- Vocabulary: Vocabulary for the use of route guidance and information should incorporate various psychological considerations. Drivers should not be alienated through the use of unfamiliar words.

- Intonation and Inflection: Synthesized speech does not sufficiently allow the designer to vary the intonation or inflection of words and, as a result, can be fatiguing or annoying. Studies varying the length of time between words to provide hints of inflection have reduced the annoyance factor.

- Cues: Several non-verbal cues are also important when relaying information. The speaker should be perceived as sincere, helpful, and friendly rather than condescending or threatening.

- Training: Driver's perception of synthetic speech can be improved with a moderate amount of training by exposure to synthetic speech, even of lower quality. Thus drivers exposed to synthetic speech over a period of time should improve their performance of route-following tasks. The effects of training can be retained over a long intervening period.

The following recommendations have been provided as guidelines for developing an effective Highway Advisory Radio message (Dudek et al., 1983):

• Lengthy dialogs should be avoided when route information is delivered. Subjects in the study performed better with a terse message style.

• The capacity of a driver to remember an unfamiliar route is limited to 4 turns and 4 names. This phenomenon could be related to short term memory capacity of 7 ± 2 (Miller, 1957).

• Repetition of the diversion route improves retention of the route information among motorists. This could be accomplished through external or internal redundancy.

• Prominent landmarks can help guide the unfamiliar motorist. Using the number of traffic lights between turns as a landmark should be done with care. Traffic lights as landmarks should be avoided when flashing lights are involved.

• Motorists familiar with a route, such as commuters, do not need as detailed a description of route change as unfamiliar drivers.

• Researchers felt the instruction "you have come too far," was helpful for drivers who inadvertently left the route, although one study indicated that subjects disliked the information (Streeter et al., 1985).

Cellular Telephones: With the widespread use of cellular telephones in automobiles, it is now feasible to consider the telephone as an in-vehicle means of incident information and route guidance. However, use of cellular telephones for this purpose poses problems. Relatively few of the total number of cars on the freeway system currently have cellular telephones. The proposed survey for this project will reveal some quantitative and qualitative data on the population using cellular telephones within the I-5 corridor.

Safety is a concern in the use of cellular telephones. A study presented at the 21st Annual Workshop on Human Factors in Transportation (Zwahlen, Adams, and Schwartz, 1987) measured the deviations of automobiles from the centerline while drivers were using cellular telephones. The study, using two different automobiles and two different mounting positions for the digital cellular telephone, concluded that the drivers' lateral deviations from the centerline were too high during the use of cellular telephones. Thus use of in-vehicle cellular telephone systems for traffic information (like use of visual dashboard displays) may compromise vehicle safety, and such systems should be assessed carefully before they are implemented.

Conclusions

Previously, the media discussed in this state-of-the-art review have been studied mainly as information sources that are independent of each other and of motorists' needs. In evaluating the usefulness of these media for supplying traffic information to freeway motorists in the Seattle area, the various information channels must be viewed as part of an integrated system consisting of technology and humans that is specifically designed to meet the complex requirements of the Seattle area freeway drivers. The information gained from the motorist surveys discussed in this report, and from the upcoming motorist survey which is the next phase of this project, should help us design a traffic information system that will enable drivers to become more efficient users of the freeway system. Information about Seattle commuters should serve as a basis for determining what media will be used in the integrated traffic information system for the Seattle area and, along with technical considerations based on information contained in this report and elsewhere, should determine the placement of the media and the content of the messages delivered by those media.

Further, this review has isolated a number of important "human" factors issues which must be considered in the design of motorist information systems. Variables such as age, visual acuity, personality type, eye scanning patterns, and mental workload, for example, all interact to determine how commuters perceive, understand, and act on information. Clearly if factors such as these are not considered in the design of information systems, the result may be a costly new piece of technology which has little impact on the behavior of Seattle commuters. The survey which will temporally follow this review is designed to answer some, but not all, of the issues reviewed here. Future extensions of this project are necessary to provide a clearer and broader description of the Seattle commuter and to determine the most effective means of providing motorist information to commuters.

Use of the sophisticated technologies described in this report will require compatibility between the various systems; thus standardization is an issue that must be considered in designing an integrated traffic system. Any system, regardless of the forms in which it currently presents information, should be compatible with emerging technologies so that the system does not become obsolete.

Ultimately, however, motorist information systems must be user-based. The designer of an effective system must first know who the drivers are, what decisions they make, where and on what basis these decisions are made, and what predispositions drivers have towards the delivery of information about these decisions. This state of the art review is only the first step towards answering these questions.

APPENDIX II
THE FAME MOTORIST INFORMATION SURVEY

APPENDIX IIA
THE FAME MOTORIST INFORMATION SURVEY QUESTIONAIRE

Motorist Information Survey

The Washington State Department of Transportation and the University of Washington are working together to improve the traffic information you receive before and during your travel on Seattle area freeways. To make traffic information more effective for you, we need to know about your commute and use of traffic information. Please fill out this questionnaire carefully, selecting the most appropriate answers for your situation. Feel free to add short comments to the right of your answer if it requires explanation. All responses are confidential.

A. Your Commute

1. In an average week, how many **days** do **you drive I-5** to or from **work** anywhere between Lynnwood and downtown Seattle?

   ❑ 7 ❑ 6 ❑ 5 ❑ 4 ❑ 3 ❑ 2 ❑ 1 ❑ **0**

   (If zero, please skip to Section C, next page.)

2. Please tell us where you usually enter and exit I-5 when you commute.

   Southbound-- Enter I-5: ____________________
   Exit I-5: ____________________
   Northbound-- Enter I-5: ____________________
   Exit I-5: ____________________

3. Estimate your driving . . .

   Distance between home and work, excluding detours and errands: _______ miles
   Time from **home to work**, excluding detours and errands: _______ minutes
   Time from **work to home**, excluding detours and errands: _______ minutes

4. How much **flexibility** is there in the time when you . . .

   Leave **home for work** ❑ A lot ❑ Some ❑ Very little
   Leave **work for home** ❑ A lot ❑ Some ❑ Very little

5. How much **stress** do you experience during your usual commute to and from work?

   ❑ A lot ❑ Some ❑ Very little

6. During your commute, how much importance do you place in . . .

   Saving commute time ❑ A lot ❑ Some ❑ Very little
   Reducing commute distance ❑ A lot ❑ Some ❑ Very little
   Increasing commute safety ❑ A lot ❑ Some ❑ Very little
   Increasing commute enjoyment ❑ A lot ❑ Some ❑ Very little

7. How many people (including yourself) usually are in the car when you commute?

   ❑ 5 or more ❑ 4 ❑ 3 ❑ 2 ❑ 1

B. Your Route Choices

1. How **familiar** are you with north/south routes that can be used as alternatives to I-5?

   ❑ Very ❑ Somewhat ❑ Not at all

2. How often do you modify or change the route you travel from . . .

   Home to work ❑ Frequently ❑ Sometimes ❑ Rarely
   Work to home ❑ Frequently ❑ Sometimes ❑ Rarely

More ☞

3. How often do the following factors affect your choice of commuting routes?

	Frequently	Sometimes	Rarely
Traffic reports and messages	❑	❑	❑
Actual traffic congestion	❑	❑	❑
Time of day	❑	❑	❑
Weather conditions	❑	❑	❑
Time pressures	❑	❑	❑

Comments:

4. Where are you most likely to choose your commuting route? (Check one only.)

❑ At home or work ❑ On city streets ❑ Near entrance ramps ❑ On I-5

5. When you are commuting, what length of delay on I-5 would cause you to divert to . . .

An alternate route that you know ________ minutes

An alternate route that you do not know ________ minutes

C. Traffic Information

1. From which media have you **ever** received traffic information?

(Check all that apply in each column.)

	Column A Before driving	Column B While driving
TV	❑	---
Electronic message sign over I-5	---	❑
Advisory radio indicated by flashing lights on highway sign	---	❑
Commercial radio station	❑	❑
Phone	❑	❑
CB Radio	❑	❑
None	❑	❑

2. From which medium would you **prefer** to receive traffic information?

(Check one only **in each column.**)

	Column A Before driving	Column B While driving
TV	❑	---
Electronic message sign over I-5	---	❑
Advisory radio indicated by flashing lights on highway sign	---	❑
Commercial radio station	❑	❑
Phone	❑	❑
CB Radio	❑	❑

3. How much **help** do you get from traffic information delivered by . . .

	A lot	Some	Very little	Never used
TV	❑	❑	❑	❑
Electronic message sign over I-5	❑	❑	❑	❑
Advisory radio indicated by highway sign	❑	❑	❑	❑
Commercial radio station	❑	❑	❑	❑
Telephone highway construction hot line	❑	❑	❑	❑

4. **When you are on I-5**, how often does **traffic information** cause you to divert to an alternate route?

❑ Frequently ❑ Sometimes ❑ Rarely ❑ Never receive information

Comments:

5. **Before you drive**, how often does **traffic information** influence . . .

	Frequently	Sometimes	Rarely	Never receive
The time you leave	❑	❑	❑	❑
Your means of transportation (e.g., car, bus)	❑	❑	❑	❑
Your route choice	❑	❑	❑	❑

6. At what point do you **prefer** to receive traffic information? (Check one only.)

❑ Before driving ❑ On city streets ❑ Near entrance ramps ❑ On I-5

7. If continual up-to-the-minute traffic information were available in the following ways, would you use them?

Traffic information delivered via phone hot line	❑ Yes	❑ No
Radio station dedicated to traffic information	❑ Yes	❑ No
Traffic information delivered via computer	❑ Yes	❑ No
Cable TV station dedicated to traffic information	❑ Yes	❑ No

8. Which of these services would you like to see developed first? (Check one only.)

❑ Traffic information delivered via phone hot line
❑ Radio station dedicated to traffic information
❑ Traffic information delivered via computer
❑ Cable TV station dedicated to traffic information

9. Which of the following are available to you? (Check all those items that are usually in working order.)

Radio:	❑ Home	❑ Office	❑ Car
Phone:	❑ Home	❑ Office	❑ Car
TV:	❑ Home	❑ Office	
TV cable hook-up:	❑ Home	❑ Office	
Computer:	❑ Home	❑ Office	

D. For Classification Purposes

1. What is your home Zip Code? ____________ Your work Zip Code? __________
2. Are you: ❑ Male ❑ Female
3. What is your age? ❑ Under 31 ❑ 31-40 ❑ 41-50 ❑ 51-64 ❑ 65 and over
4. What is the annual income, before taxes, for your entire household?

	Total Household
No income	❑
Under $10,000	❑
10,000-19,999	❑
20,000-29,999	❑
30,000-39,999	❑
40,000-49,999	❑
50,000-59,999	❑
60,000-74,999	❑
75,000-100,000	❑
Over 100,000	❑

☞

5. Would you be willing to take part in a follow-up interview about your use of traffic information? If so, please fill out the following. A more detailed discussion of your commute would help us improve your travel on Seattle freeways. All information will be kept confidential.

Name: ____________________

Occupation: ____________________

Address: ____________________

Phone number at: Home ______________ Work ______________

Thank you very much for participating in this effort to improve Seattle traffic information.

Please fold with Business Reply mailer on outside and staple/tape on line below.
Drop in a mailbox. No stamp is necessary.

Motorist Information Survey

Washington State
Department of Transportation

University of Washington

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 155 OLYMPIA, WA

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Public Transportation Office
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APPENDIX IIB
THE FAME MOTORIST INFORMATION SURVEY METHOD CHOICE

Survey Method

Five survey methods were evaluated. All methods were weighed against the following criteria: time frame for accessing motorists, potential response rate and/or bias, accuracy of contacting the desired sample frame, and time differential between time of commute and receipt of survey. The off ramp method would allow us to (1) access motorists easily and without much delay, (2) obtain a high response rate, (3) obtain a representative sample, and (4) reduce the time between motorists' commute and receipt of the survey. The five methods we evaluated are described below.

1. Geographical Selection by Business Location

   This method required questionnaire distribution and data collection at specific building sites in downtown Seattle. Access to potential participants in these buildings would have to be handled through the city's building transportation coordinators. This method required potentially cumbersome coordination for access to participants, and targeting of north I-5 corridor commuters would be complex. Further, a potential sample bias could occur in that only buildings with large populations have transportation coordinators.

2. License Plate Survey Method

   This method required recording license plate numbers of motorists on the I-5 north corridor during the morning rush-hour and then acquiring motorist names, addresses, and phone numbers from the Washington State Department of Motor Vehicle Licensing. This method was very labor intensive, could provide inaccurate sampling since people often move or list incorrect addresses, would require a large time differential between commute time and survey receipt, and would be impersonal.

3. Geographical Selection by Home Address or Telephone

   This method required door-to-door sampling, a selected mailing, and/or telephone solicitation. It would be very labor intensive, have some population targeting problems, and require a large time differential between commute time and survey receipt.

4. General Distribution

   This method required placing the survey in the Sunday newspaper. It would produce a high number of extraneous respondents. Furthermore, the distribution method would be impersonal and the time differential between commute time and survey receipt would be large.

5. On-Road Solicitation Method

   This method involved acquiring potential respondents by accessing them at freeway off ramps. While somewhat labor intensive, this method was selected because it offered an in-person distribution method during commute time, a timely distribution method, and accurate targeting of the correct sample frame.

After we identified specific details of these methods, our design team individually assigned ratings to each method based on the stated criteria; these averaged ratings appear in Table 1.

Rating of Distribution Methods (5=high and 1=low)

Method	Evaluation Criteria Time Frame	Sample Accuracy	Response Proximity	Method Complexity	In-person Method	Total Rating
Business location	2	3	3	3	5	16
License Plate ID	1	4	1	2	2	10
Address or Tele. #	3	2	1	1	3	10
Newspaper	5	1	1	5	1	13
Off-Ramps	4	4	5	3	4	20

APPENDIX III
VARIABLE NUMBERS AND NAMES

1 No./wk. driving I-5 to work
2 Entry location to I-5 S bound
3 Entry location to I-5 N bound
4 Distance home-work
5 Driving time home-work
6 Driving time work-home
7 Flexibility in time leaving home for work
8 Flexibility in time leaving work for home
9 Stress during commute to and from work
10 Impt. placed on saving commute time
11 Impt. placed on reducing commute distance
12 Impt. placed on increasing commute safety
13 Impt. placed on increasing commute enjoyment
14 No. people in car when commuting
15 Familiarity with alt. N/S rtes
16 Freq. of changing rte. to work
17 Freq. of changing rte. to home
18 Freq. of traffic info. affecting rte. choice
19 Freq. of traffic congestion affecting rte. choice
20 Time of day affecting commuting rte.
21 Weather affecting commuting rte.
22 Time pressure affecting commuting rte.
23 Where commuting rte.is chosen
24 Delay length causing diversion to known alt rte.
25 Delay length causing diversion to unknown alt rte.
26 Receive traffic info. via TV
27 Receive traffic info. via VMS
28 Receive traffic info. via HAR
29 Receive traffic info. via commercial radio
30 Receive info. by phone
31 Receive traffic info. via CB
32 Never receive traffic info.
33 Preferred media for receiving traffic info. before commute
34 Preferred media for receiving traffic info. during commute
35 Helpfulness of TV traffic info.

36 Helpfulness of VMS traffic info.
37 Helpfulness of HAR traffic info.
38 Helpfulness of commercial radio traffic info.
39 Helpfulness of phone traffic info.
40 On I-5, frequency that info. causes rte. diversion
41 Before driving, traffic info. influences time leaving
42 Before driving, traffic info. influences mode
43 Before driving, traffic info. influences rte. choice
44 Preferred time to receive traffic info.
45 Anticipated use of phone hot line for tr. info.
46 Anticipated use of dedicated radio station for tr. info.
47 Anticipated use of computer for tr. info.
48 Anticipated use of cable TV for tr. info.
49 Preference for medium developed first
50 Availability of radio in home, office, car
51 Availability of phone in home, office, car
52 Availability of TV in home or office
53 Availability of cable TV hook-up in home or office
54 Availability of computer in home or office
55 Home Zip code
56 Work Zip code
57 Gender
58 Age
59 Household income
60 Willingness to participate in follow-up interview
61 Comments

APPENDIX IV:
PEARSON AND SPEARMAN CORRELATION MATRICES

Appendix IVa. Pearson Correlation Matrix of Selected Variables (see notes below)

Var #		1	2	3	4	5	6	14	24	25	58
1	Number of times/wk. driving I-5 to work										
2	Entry location to I-5 S bound	-0.01									
3	Entry location to I-5 N bound	-0.02	0.94*								
4	Distance home-work	0.01	0.63*	0.63*							
5	Driving time home-work	-0.01	0.45*	0.45*	0.75*						
6	Driving time work-home	-0.01	0.43*	0.43*	0.70*	0.85*					
14	No. people in car when commuting	0.05*	0.04*	0.04"	0.05*	0.02	0.02				
24	Delay length causing diversion to known alt. rte.	0.00	0.21*	0.20*	0.23*	0.26*	0.26*	0.02			
25	Delay length causing diversion to unknown alt. rte.	0.00	0.16*	0.15*	0.19*	0.24*	0.22*	0.03"	-0.24*		
58	Age	-0.03"	-0.04"	-0.03"	0.01	0.04"	0.03	-0.05*	-0.04*	-0.07*	
59	Household income	0.01	-0.12*	-0.12*	-0.07*	-0.02	-0.03"	0.02	-0.04*	-0.06*	0.29*

Notes: " after correlation values represents $p \leq .01$
* after correlation values represents $p \leq .001$

Appendix IVb. Spearman Correlation Matrix of Selected Variables (see notes below)

Variable		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VAR1	No./Wk. driving I-5 to work																				
VAR2	Entry location to I-5 S bound	.03"																			
VAR3	Entry location to I-5 N bound	.03	.94*																		
VAR4	Distance home-work	.00	.50*	.52*																	
VAR5	Driving time home-work	-.02	.37*	.38*	.81*																
VAR6	Driving time work-home	-.02	.34*	.36*	.76*	.86*															
VAR7	Flexibility in time leaving home for work	.02	-.07*	-.06*	-.06*	-.09*	-.07*														
VAR8	Flexibility in time leaving work for home	.01	-.10*	-.08*	-.13*	-.13*	-.16*	.42*													
VAR9	Stress during commute to and from work	.06*	.14*	.16*	.26*	.31*	.31*	-.12*	-.13*												
VAR10	Impt. placed on saving commute time	.04	.03	.03	.13*	.16*	.16*	-.08*	-.10*	.28*											
VAR11	Impt. placed on reducing commute distance	.04	.00	-.02	-.01	-.01	-.01	-.06*	-.09*	.14*	.29*										
VAR12	Impt. placed on increasing commute safety	-.02	.05*	.04"	.05"	.02	.03	-.05"	-.08*	.06*	.02	.21*									
VAR13	Impt. placed on increasing commute enjoyment	.01	.05"	.05"	.11*	.10*	.12*	-.01	-.05"	.19*	.12*	.17*	.35*								
VAR14	No. people in car when commuting	.05*	.08*	.10*	.05"	.01	.01	-.14*	-.11*	.06*	.02	.04	.04"	.02							
VAR15	Familiarity with alt. N/S routes	.04"	-.01	.01	-.12*	-.15*	-.14*	.06*	.06*	-.05"	-.05"	-.05"	-.01	-.02	.04						
VAR16	Freq. of changing rte. to work	-.02	-.04	-.03	-.02	.01	-.02	.09*	.07*	.06*	.03	.05"	.03	.06*	-.01	.17*					
VAR17	Freq. of changing rte. to home	.00	-.13*	-.11*	-.14*	-.11*	-.06*	.07*	.12*	.05"	.01	.02	.01	.05*	-.02	.23*	.41*				
VAR18	Freq. of traffic info. affecting rte. choice	.01	.02	.02	.06*	.06*	.07*	.04"	.03	.11*	.10*	.07*	.05"	.06*	-.02	.13*	.31*	.26*			
VAR19	Freq. of traffic congestion affecting rte. choice	.03	-.08*	-.10*	-.14*	-.12*	-.08*	.12*	.07*	.09*	.11*	.12*	.06*	.06*	-.03	.18*	.32*	.39*	.40*		
VAR20	Time of day affecting commuting rte.	-.01	-.10*	-.08*	-.08*	-.07*	-.04"	.08*	.10*	.07*	.09*	.12*	.05"	.11*	-.06*	.13*	.28*	.34*	.26*	.41*	
VAR21	Weather affecting commuting rte.	-.02	.03	.03	.05"	.06*	.06*	.00	-.02	.07*	.02	.11*	.10*	.07*	-.02	.09*	.22*	.21*	.27*	.29*	.40*
VAR22	Time pressure affecting commuting rte.	-.01	-.02	-.03	-.04	-.01	.01	-.02	.00	.15*	.12*	.19*	.08*	.13*	-.03	.07*	.23*	.24*	.27*	.39*	.47*
VAR24	Delay length causing diversion to known alt. rte.	.00	.19*	.19*	.30*	.30*	.29*	-.05"	-.08*	.06*	-.02	-.02	.07*	.02	.03	-.16*	-.21*	-.31*	-.14*	-.30*	-.17*
VAR25	Delay length causing diversion to unknown alt. rte.	-.01	.13*	.13*	.25*	.25*	.24*	-.07*	-.08*	.05"	-.03	-.02	.07*	.00	.02	-.17*	-.18*	-.25*	-.10*	-.23*	-.14*
VAR35	Helpfulness of TV traffic info.	-.04	.04	.02	.00	-.03	-.03	.01	-.04	.02	.01	.06*	.10*	.03	.07*	-.02	.06"	.00	.10*	.04"	.07*
VAR36	Helpfulness of VMS traffic info.	.01	.1*	.07*	-.05"	-.08*	-.07*	.00	-.02	-.01	-.02	.06*	.09*	.04	.00	-.01	.00	-.01	.03	.07*	.08*
VAR37	Helpfulness of HAR traffic info.	-.03	.01	-.01	.05"	.02	.04	.01	-.02	.03	-.01	.06*	.07*	.06"	.05"	-.01	.03	.01	.12*	.05"	.11*
VAR38	Helpfulness of commercial radio traffic info.	-.03	.03	.02	.08*	.05"	.07*	.00	-.01	.02	.03	.04"	.08*	.08*	.01	.07*	.11*	.10*	.45*	.15*	.10*
VAR39	Helpfulness of phone traffic info.	.02	.01	.00	-.01	-.03	-.02	.02	-.02	-.01	-.01	.03	.04	.00	.02	.00	.04"	.03	.06"	.03	.06*
VAR40	On I-5, frequency that info. causes rte. diversion	-.01	.04	.03	.00	.01	.03	.05"	.04"	.13*	.11*	.09*	.05"	.08*	-.01	.16*	.28*	.29*	.44*	.39*	.27*
VAR41	Before driving, traffic info. influences time leaving	-.02	.07*	.06*	.11*	.12*	.12*	-.01	-.01	.13*	.07*	.10*	.11*	.13*	.00	-.06*	.07*	.04	.25*	.08*	.15*
VAR42	Before driving, traffic info. influences mode	-.05*	.03	.02	-.01	.00	.01	-.02	-.07*	.03	.00	.07*	.06*	.05"	.09*	-.04"	.02	-.04"	.06*	.00	.03
VAR43	Before driving, traffic info. influences rte. choice	-.07*	-.04	-.05"	-.02	.00	.00	.04"	.04	.09*	.08*	.09*	.07*	.09*	.00	.12*	.33*	.30*	.47*	.35*	.29*
VAR45	Anticipated use of phone hot line for traffic info.^	-.03	-.01	-.01	-.02	-.01	.01	-.01	-.01	.07*	.12*	.11*	.04"	.08*	-.03	-.03	.02	.02	.08*	.09*	.09*
VAR46	Anticipated use of dedicated radio for traffic info.^	-.01	.03	.03	.06*	.05"	.08*	.00	-.02	.08*	.06*	.03	.07*	.07*	-.01	.06*	.06*	.07*	.15*	.10*	.07
VAR47	Anticipated use of computer for traffic info.^	.01	-.02	-.01	.03	.03	.04	.04"	.02	.03	.03	.04	.04	.07*	.01	.01	.03	.05"	.07*	.06*	.08*
VAR48	Anticipated use of cable TV for traffic info.^	.02	.09*	.08*	.05"	.04	.04	-.04"	-.05"	.05"	.07*	.07*	.10*	.08*	.03	-.08*	-.01	-.03	.08*	.04	.06*
VAR57	Gender°	.05"	-.02	.00	.04"	.01	.00	.16*	.11*	-.06*	-.09*	-.12*	-.13*	-.07*	.01	.19*	.09*	.02	-.01	-.02	-.01
VAR58	Age	-.04"	-.04"	-.04	.02	.04"	.03	.07*	.04	-.09*	-.12*	-.08*	.08*	-.02	-.06*	.13*	.05"	-.02	.05"	.00	-.07*
VAR59	Household income	.01	-.14*	-.14*	-.06*	-.02	-.02	.14*	.12*	-.07*	.00	-.10*	-.09*	-.08*	.03	.09*	.04"	.00	.03	-.02	-.07*
VAR60	Willingness to participate in follow-up interview^	.05*	.08*	.08*	.09*	.09*	.10*	.01	.02	.07*	.09*	.01	-.01	.06*	.05"	.03	.04	.04	.05*	.06*	.02
Variable		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

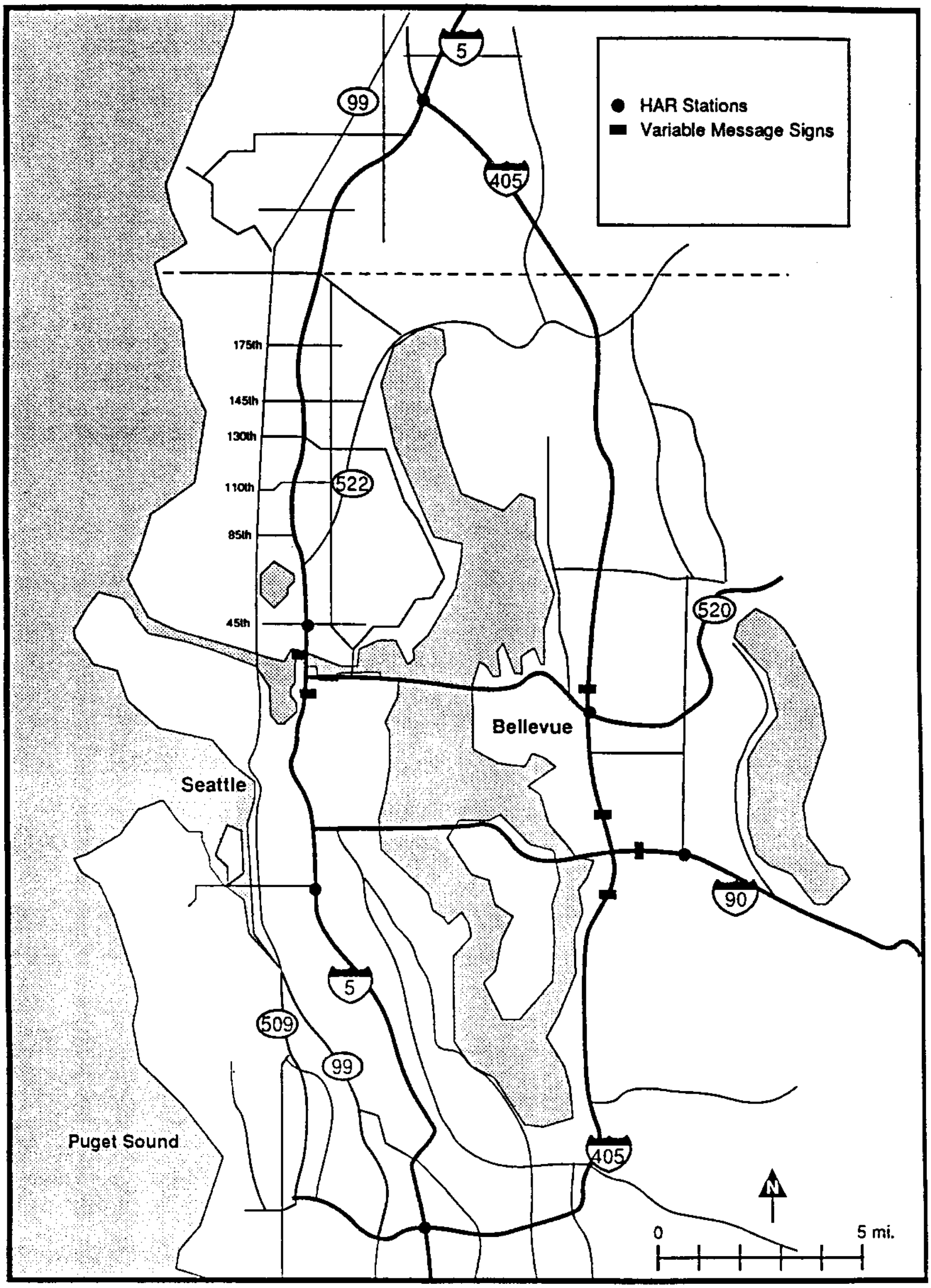
Notes:
" after correlation values represents $p \leq .01$
* after correlation values represents $p \leq .001$
^ coding for these variables: 1 = yes, 2 = no
° coding for this variable: 0 = female, 1 = male

Appendix IVb cont. Spearman Correlation Matrix of Selected Variables (see notes below)

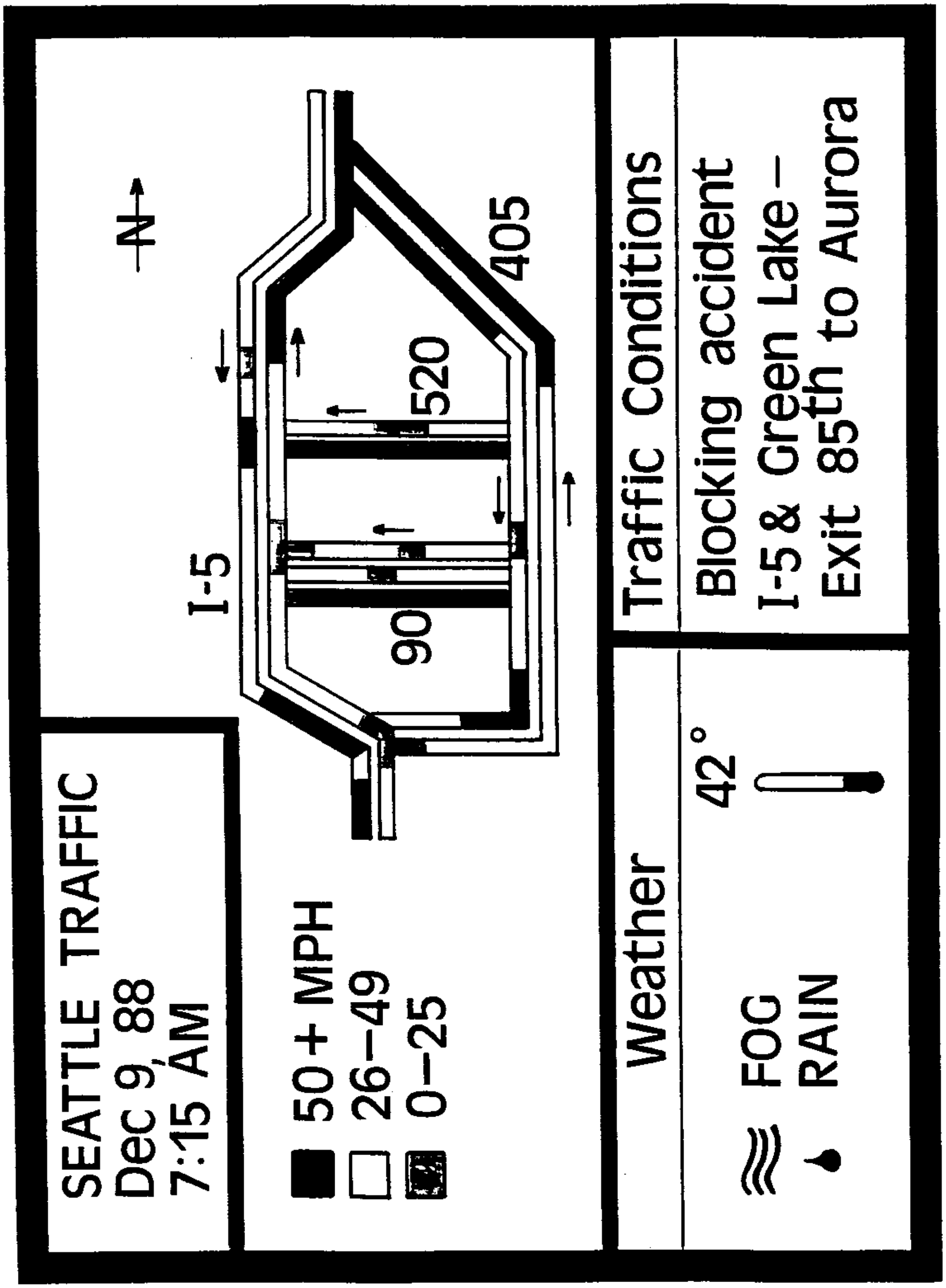
Variable		21	22	24	25	35	36	37	38	39	40	41	42	43	45	46	47	48	57	58	59
VAR22	Time pressure affecting commuting rte.	.40*																			
VAR24	Delay length causing diversion to known alt. rte.	-.08*	-.13*																		
VAR25	Delay length causing diversion to unknown alt. rte.	-.08*	-.10*	.78*																	
VAR35	Helpfulness of TV traffic info.	.10*	.09*	.04	.02																
VAR36	Helpfulness of VMS traffic info.	.05"	.09*	-.02	.01	.13*															
VAR37	Helpfulness of HAR traffic info.	.10*	.07*	.03	.02	.13*	.44*														
VAR38	Helpfulness of commercial radio traffic info.	.14*	.12*	-.01	.01	.11*	.09*	.17*													
VAR39	Helpfulness of phone traffic info.	.08*	.08*	.00	-.01	.12*	.13*	.19*	.03												
VAR40	On I-5, frequency that info. causes rte. diversion	.22*	.27*	--.17*	-.16*	.10*	.12*	.15*	.31*	.05"											
VAR41	Before driving, traffic info. influences time leaving	.19*	.20*	.08*	.06"	.22*	.10*	.18*	.25*	.08*	.20*										
VAR42	Before driving, traffic info. influences mode	.09*	.06*	.05"	.04	.16*	.12*	.11*	.10*	.08*	.07*	.33*									
VAR43	Before driving, traffic info. influences rte. choice	.26*	.29*	-.14*	-.12*	.16*	.10*	.17*	.31*	.08*	.46*	.47*	.29*								
VAR45	Anticipated use of phone hot line for traffic info.^	.07*	.15*	.00	.01	.05"	.07*	.10*	.03	.09*	.09*	.15*	.09*	.12*							
VAR46	Anticipated use of dedicated radio for traffic info.^	.07*	.08*	.01	.02	.04"	.06*	.12*	.15*	.02	.15*	.12*	.05"	.15*	.12*						
VAR47	Anticipated use of computer for traffic info.^	.06*	.07*	-.02	.00	.07*	.07*	.12*	.02	.04	.09*	.07*	.03	.06*	.21*	.08*					
VAR48	Anticipated use of cable TV for traffic info.^	.10*	.09*	.04	.02	.29*	.09*	.09*	.07*	.02	.07*	.17*	.09*	.10*	.17*	.13*	.20*				
VAR57	Gender°	-.08*	-.10*	-.05"	-.09*	-.05"	-.10*	.01	-.02	.03	-.02	-.14*	-.11*	-.04"	-.11*	-.01	.02	-.05"			
VAR58	Age	.04"	-.09*	-.05"	-.08*	-.06*	-.06*	-.05"	.05"	.01	-.02	-.04	.00	.02	-.07*	.00	-.05*	.09*	.20*		
VAR59	Household income	-.04"	-.13*	--.05"	-.08*	-.06*	-.13*	-.07*	-.01	.01	-.02	-.12*	-.07*	-.02	-.05"	-.01	.01	.07*	.21*	.31*	
VAR60	Willingness to participate in follow-up interview^	.03	.03	-.01	-.01	.00	.02	.05"	.05"	.02	.05*	.05*	.01	.05*	.06*	.02	.06*	.03	.02	.03	.01
Variable		21	22	24	25	35	36	37	38	39	40	41	42	43	45	46	47	48	57	58	59

Notes:
" after correlation values represents $p \leq .01$
* after correlation values represents $p \leq .001$
^ coding for these variables: 1 = yes, 2 = no
° coding for this variable: 0 = female, 1 = male

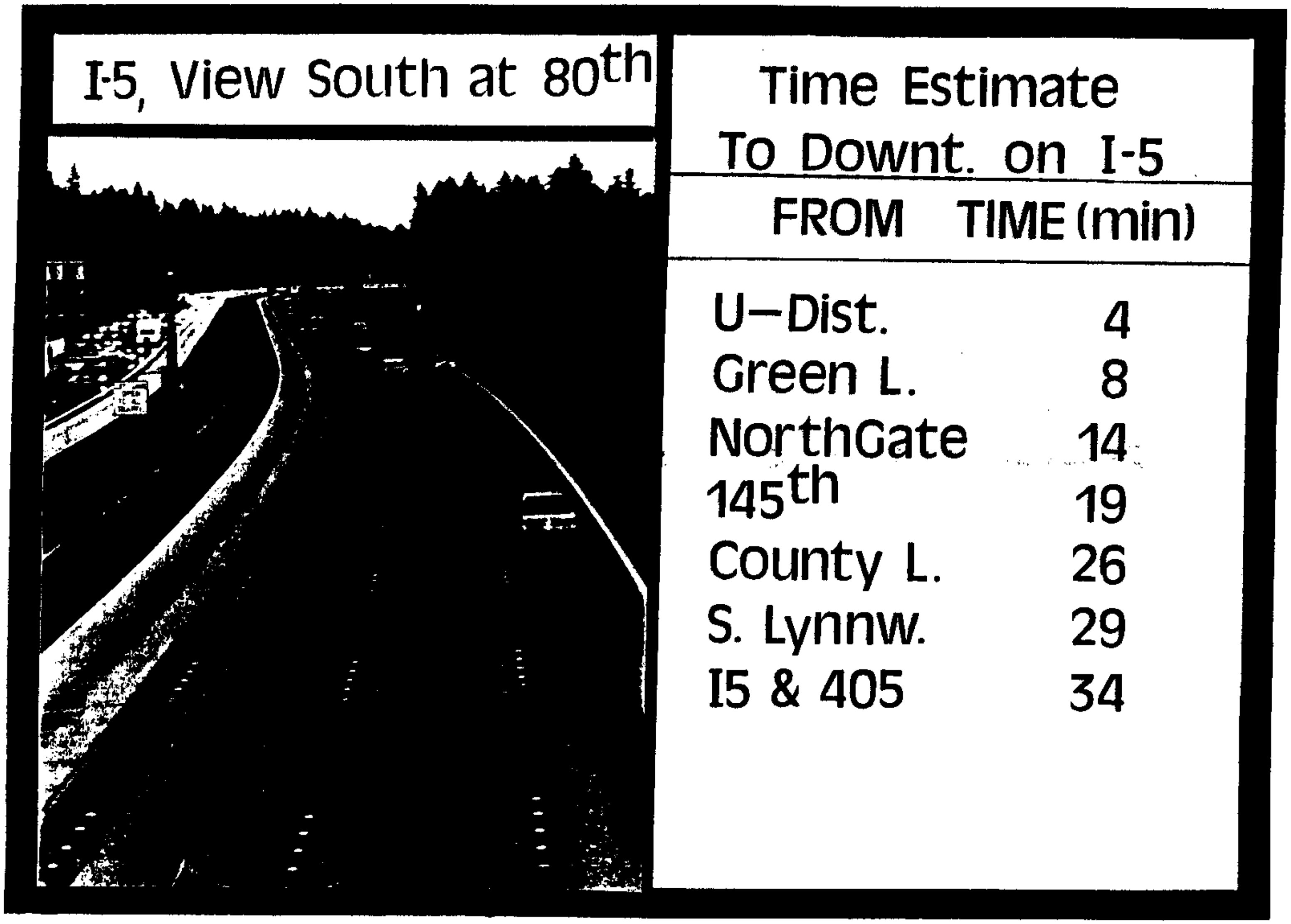
APPENDIX V:
MAP OF SEATTLE AREA FREEWAYS WITH MAJOR ON-RAMPS


HAR Stations
Variable Message Signs
5
99
405
175th
145th
130th
110th
522
85th
45th
520
Bellevue
Seattle
90
5
509
99
Puget Sound
405
N
0
5 mi.

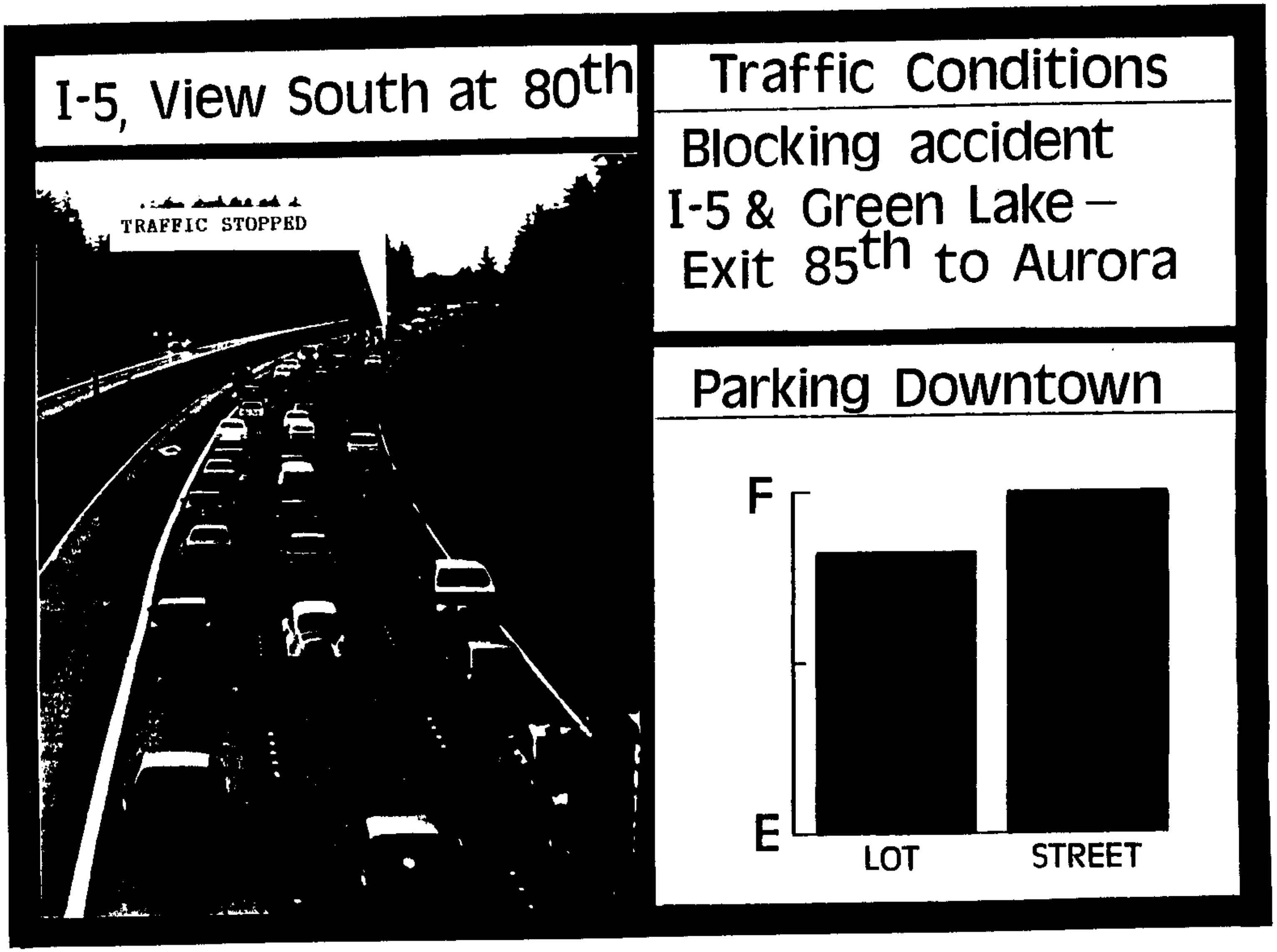
APPENDIX VI:
SCREENS FOR THE GRAPHICS QUESTIONAIRE


SEATTLE TRAFFIC
Dec 9, 88
7:15 AM
50+ MPH
26–49
0–25
N
I-5
520
90
405
Traffic Conditions
Blocking accident
I-5 & Green Lake –
Exit 85th to Aurora
Weather
42°
FOG
RAIN

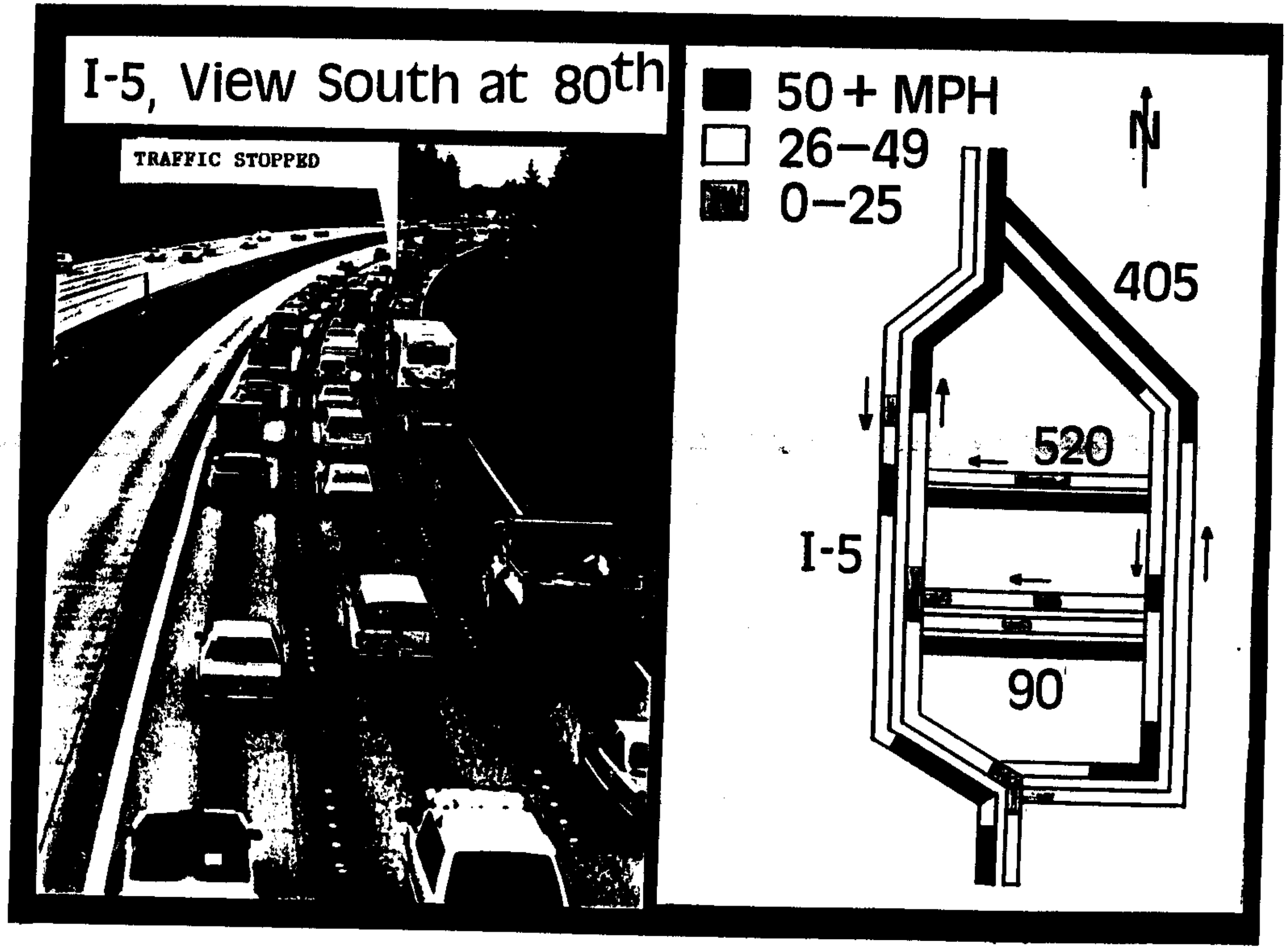
SCREEN 1.


I-5, View South at 80th
Time Estimate
To Downt. on I-5
FROM TIME (min)
U–Dist. 4
Green L. 8
NorthGate 14
145th 19
County L. 26
S. Lynnw. 29
I5 & 405 34

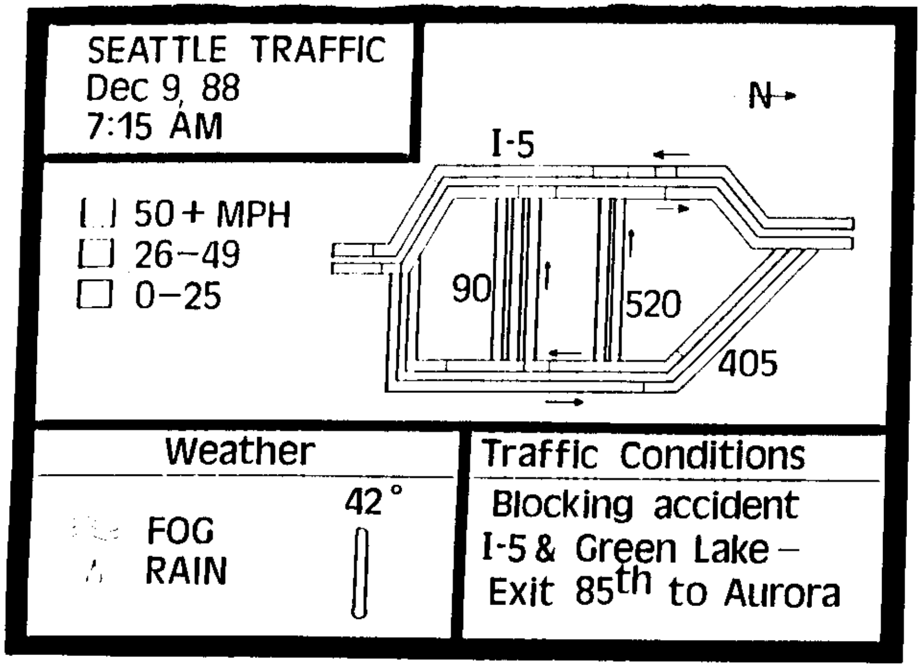
SCREEN 2.


I-5, View South at 80th
TRAFFIC STOPPED
Traffic Conditions
Blocking accident
I-5 & Green Lake –
Exit 85th to Aurora
Parking Downtown
F
E
LOT
STREET

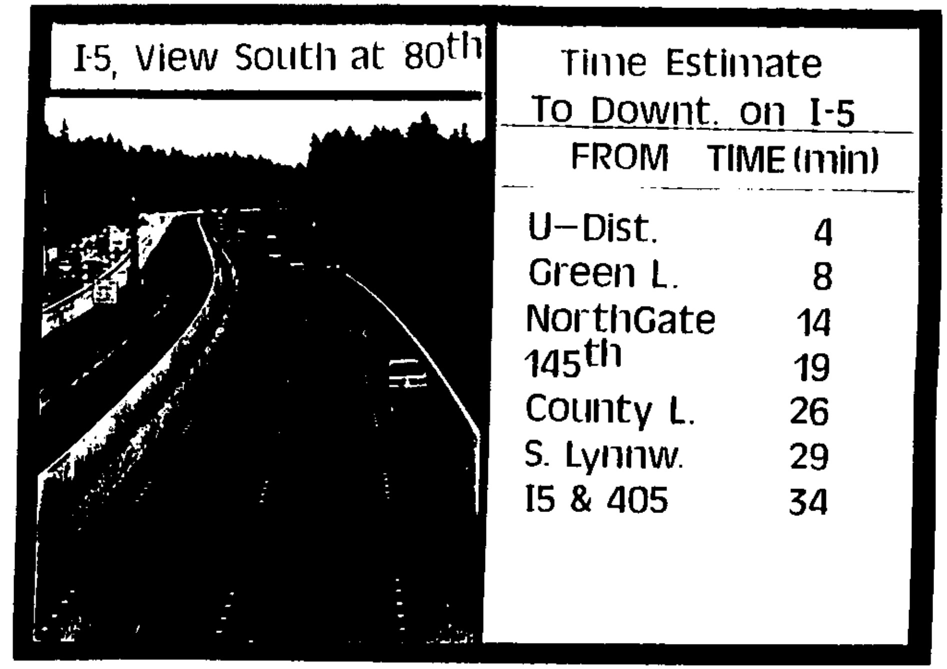
SCREEN 3.


I-5, View South at 80th
TRAFFIC STOPPED
50 + MPH
26–49
0–25
N
405
520
90
I-5

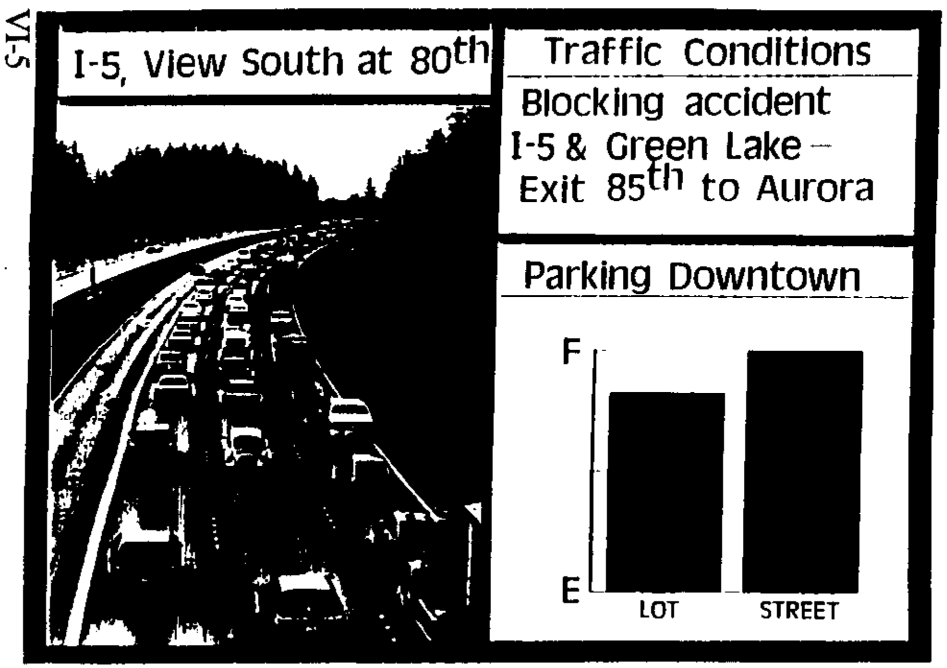
SCREEN 4.



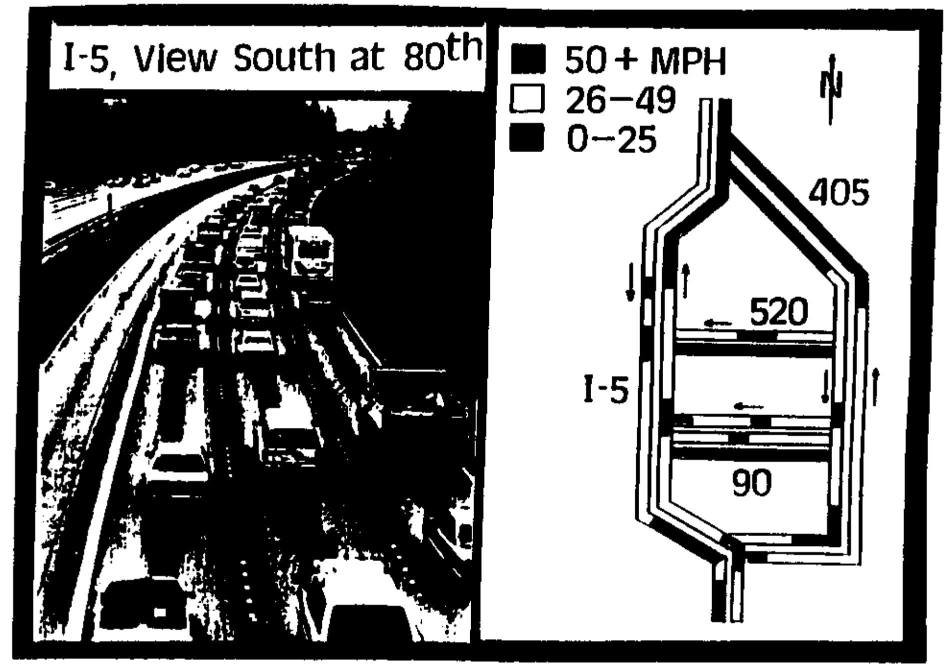
SCREEN 1



SCREEN 2



SCREEN 3



SCREEN 4

APPENDIX VII:
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