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Understanding and Predicting Traveler Response to Information: A Literature Review

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1 BACKGROUND

1.1 Introduction

In the early days of automobiles when, for the first time in history, large numbers of people had opportunities to travel well beyond their local areas, finding directions was a problem. Prior to that, the range of most peoples' travels was limited to a relatively short distance from their home, and people quickly became familiar with the small network that they regularly used. Signage was not needed. However, as new drivers roamed into unfamiliar areas, the lack of signage made getting lost a common occurrence.

Technology soon provided solutions to this problem (French 1986). For example, it was possible to buy and install an in-vehicle cylindrical or disc-shaped device that advanced at a rate that was synchronized with wheel rotation. The cylinders or discs had way-finding information printed on them. When initialized with the correct trip starting location, information about the direction options at each major decision point would be displayed prior to arriving there. Some enhanced versions also included static travel information such as road conditions, and locations of unimproved railroad crossings and speed traps.

Over time, of course, major investments in signage and road maps made such devices less useful, and research in traveler information systems was limited to relatively specialized applications such as for military vehicles. It is only relatively recently, with traffic congestion and the externalities of automobile use becoming more of a concern, that "advanced" traveler information systems (ATIS), have again become of interest. Technological progress in vehicle location, traffic monitoring, and data processing and communications have made possible applications that were probably not imaginable in the early days of the field.

Travel-related messages may be derived from static or dynamic information about the network. Static messages provide fixed information about the network and the destinations that it serves, and may be of use in tasks such as way-finding or preliminary trip planning; however, they do not recognize actual traffic conditions and so cannot respond to them. Dynamic messages reflect either prevailing or predicted conditions on the network, and require capabilities for collecting and possibly processing network data in real time. Such messages may describe the network conditions, or make recommendations based on the conditions, or both. A variety of presentation media (graphical, spoken or text) and levels of quantitative or qualitative detail in the messages are possible.

With these recent enhancements of traveler information system technological capabilities has also come an increased interest in understanding how travelers react to information provided in this way. There are many reasons for this interest:

- public and private organizations developing travel information products need to know what product features are most valued by travelers and why; this knowledge enables better products to be designed, and appropriate pricing strategies to be elaborated;

- public agencies investing in travel information infrastructure also need to know how travelers perceive and value the benefits that they will derive from the provided information, as guidance in making economically worthwhile investment decisions;

- many of these same agencies are examining the contribution that traveler information systems may make towards improving the overall operation and performance of their transportation systems, either by themselves or in combination with advanced traffic management systems (ATMS). Such network-level ATIS impacts can best be determined by aggregating the individual responses of many travelers to the information that they are provided by ATIS, but in doing this the interactions of the travelers on the network may become important and then must also be taken into account;

- finally, ATIS technologies currently under development will eventually be able to provide information based on predictions of future travel conditions; however, such information must incorporate a forecast of how travelers will react to it. For example, on the basis of short-term traffic forecasts, an ATIS may inform drivers that a certain route is expected to become congested in the next hour. If drivers react to this information by choosing a different route, their response may invalidate the forecast, leaving the original route free flowing but creating even worse congestion on an alternate route. Generating guidance based on forecast traffic conditions requires being able to forecast how drivers will respond to the guidance that they receive, determining the aggregate network-level impacts of the responses, and incorporating those responses and impacts into the guidance itself.

1.2 Scope and purpose of this document

In view of these reasons for an interest in traveler response to information, the Federal Highway Administration commissioned a review of published information on the subject; this report is one of the products of the study. It is a review of the literature published as of mid-2001 on the topic of traveler response to real-time information at the individual and network levels. (Static travel information is only considered in passing because of its rather limited scope for improving individual decisions or affecting network conditions.) The report's intent is to summarize what is currently known about traveler response to information, in a form that provides a useful high-level understanding of the main issues.

This is not a comprehensive review – it could not possibly be, given the volume of material that has been (and continues to be) published in relevant areas. Several criteria were applied in deciding what to review:

- recent (past few years) publications with relevant research or applications results;
- publications providing summaries of long-term research or operational programs;
- selected early (pre-1990) publications, chosen for their historical interest or because their results are still relevant;
- selected publications from the mid-1990s, again chosen for their relevance or historical interest.

It will be seen that, despite the number of publications in the field, understanding of traveler response to ATIS is still in its initial stages. No one is yet able to accurately predict, for a VMS displaying a particular message at a particular location in a particular network, what the effect on individual travelers or on overall network conditions will be. Only limited data is available on individual responses to information, from operational deployments or from surveys investigating user reactions to hypothetical systems. Available data tends to be concentrated in specific areas such as commuter driving behavior; much less is known about information effects on non-commute trips, transit riders and commercial vehicle operators, for example. Efforts to develop models of traveler response based on these data are, for the most part, cutting-edge academic research far removed from the capabilities and needs of mainstream practitioners. Network-level forecasting models capable of predicting ATIS system impacts are also still mostly *ad hoc* in nature, frequently involving the cobbling together of two different model systems.

This state of affairs is not entirely surprising. Automobiles and modern transit systems were in use for roughly half a century before systematic and comprehensive travel data collection efforts were undertaken, and useful individual- and network-level transportation planning models began to be developed and routinely applied. While the pace of research and development is much faster now, a decade of experiments with ATIS is not foundation enough to support the development of a full understanding of its effects.

For these reasons, this review does not devote excessive effort to documenting the complete sets of results from available user surveys, or the full details of current model systems. For the same reasons, too, it discusses survey and analysis methods as well as with results, because robust and powerful methods will be needed to obtain further useful results in the future. At this point in the development of the field, the creation of appropriate tools and methods is just as necessary and important as their application.

This document may perhaps best be regarded as a source of raw materials that can be used in many different ways. Material can be extracted from it to prepare more specialized documents, focused on particular topics or audiences. It provides extensive references to and discussions of the published literature, enabling the original detailed results on particular subjects to be easily located. Although it mostly highlights what has been done to date, this focus also illuminates some of the gaps in current knowledge, and suggests actions that need to be taken in the future to advance the state of knowledge. In one particular area – the modeling of network-level ATIS impacts – the report makes suggestions regarding specific directions for future development approaches.

A companion document provides a number of specific recommendations for Department of Transportation actions to further knowledge in the field of traveler response to information, based in large part on the gaps identified here.

1.3 Structure of the document

This document is in two parts:

- a high-level summary of the state of the art in a number of areas related to traveler response to information. It attempts to summarize what is known in the area, and also to point out major gaps in current knowledge; and

- a series of reviews (annotated extended abstracts) of relevant documents. These documents provided the knowledge and data that were used in preparing the high-level summary.

The summary discussion covers:

- traveler behavior without information (Section 2);

- traveler behavior with information (Section 3);

- network impacts of ATIS (Section 4); and

- modeling ATIS network impacts (Section 5).

In the document reviews, a single review sometimes covers several documents because of their logical or organizational connections; frequently these are cases where a series of articles describes a line of research pursued over time. To facilitate locating particular document reviews, a listing is provided following the table of contents; it references each document with the number of the page where it is reviewed.

2 TRAVELER BEHAVIOR WITHOUT INFORMATION

Before beginning a review of the literature on the effect of information on traveler decision-making, it is worthwhile to briefly summarize current approaches and understanding of such decision-making in the absence of information. This is useful for a number of reasons.

Traveler behavior exhibits many features that do not depend in a significant way on whether information from external sources is available or not. Many of these features have been identified and elucidated through studies of behavior without external information. Furthermore, it is likely that many aspects of traveler behavior in the presence of information are variations on similar behavior without information. For example, if travelers are sensitive to travel time in selecting their travel path, it is likely that many aspects of their behavior when they have reliable information on travel times will be similar to their behavior when they had to estimate these times. However, the availability of more precise and reliable time estimates may lead to modified or new behaviors that were not present when only low-quality information could be had.

Understanding of the factors that travelers consider when making trip-related decisions, and of the relative importance of these, can suggest which types of information an ATIS should provide.

Many of the methods that have been developed over the decades to analyze traveler behavior in the absence of information remain applicable to the analysis of behavior with information, so it is worthwhile to briefly review these in the simpler no-information context.

Finally, in some ATIS technologies, travelers will make portions of their trips without information and other portions with information. Consider an ATIS that transmits traffic information over a short range only: a VMS or low power radio transmitter, for example. A driver might leave home having made her travel decisions without input from the ATIS, and only receive reliable real-time information in the middle of her trip. The trip thus consists of two portions: an initial segment without information, and a final segment with information. Accurate predictions of driver behavior and of the network impacts of ATIS would require reliable models of decision-making in both contexts.

In short, traveler behavior with information cannot be understood without knowing something about traveler behavior without information.

2.1 Route choice

Transportation professionals since the beginning have had to consider the question of traveler route choice behavior, since it directly affects network-level traffic flow patterns and costs. For simplicity and convenience, any analyses have assumed that travelers choose, from among a set of alternative routes under consideration, the one that offers the lowest travel time or travel cost. From introspection and observation, however, it is not difficult to conclude that this is usually only an approximation of a more complex decision-making process.

There have been many efforts over the years to obtain a more detailed understanding of how travelers decide which routes to consider and then select one to follow. Many of these have been directed towards understanding the decision mechanism that underlies travelers' route choice behavior and establishing an appropriate modeling theory and modeling form. A number of selected research articles were reviewed to highlight some of these modeling efforts and the methods they employ.

One of the basic approaches to understand drivers' route choice behavior is descriptive data analysis. Data collected in the field and from driver surveys are used to infer drivers' route choice criteria and their relative importance drivers' decision-making processes. Descriptive statistics of the data form the basis of this approach. (Huchingson, McNees et al. 1977) and (Ratcliffe 1972) used this kind of approach to find the driving habits of the drivers – routes taken, reasons for selecting these routes, and the most important factors influencing the selection. (Heathington, Worrall et al. 1971) conducted a similar study. They found that drivers were more likely to divert to avoid delays or to save travel time on the trip to work than on the trip home; they further found that drivers were more likely to divert in order to avoid delay rather than to save travel time.

Another distinct approach in the existing literature is to use different statistical techniques like principal component factor analysis, canonical correlations, multiple regressions and grouping techniques. (Wachs 1967) used principal component factor analysis to determine whether different reasons that individuals gave to explain their route choices indicated the same or different underlying values. Respondent's attitudes were examined to determine whether they were influenced by the performance characteristics of the routes. Statistical explanation of the attitudes, in terms of driver and route characteristics, was approached by three methods: canonical correlation, multiple regression and grouping techniques. The results of these analyses are presented and conclusions are drawn regarding the dependence of attitudes toward route choice upon persons and route characteristics. (Heathington, Worrall et al. 1971) also conducted a factor analysis to determine whether relationships existed between diversion frequency and other selected respondent characteristics. However, they did not find any meaningful relationship. (Pedersen 1998) used principal component factor analysis to identify the factors that influence person's route choice. Four orthogonal factors involved in selecting automobile routes were obtained: safety, interest, purpose and hindrances. A profile analysis was also performed to find if these factors were differentially rated by men and women.

Route choice can also be modeled as a continuous variable in a variety of ways. (Duffell and Kalombaris 1998) identified the main route serving various trip origins and destinations, then used regression analysis to estimate the percentage of drivers using a route other than the main route under consideration.

Disaggregate (i.e., individual-level) choice analysis methods based on random utility models have been widely applied to model drivers' decision making processes. In the context of disaggregate route choice modeling, the routes available to a traveler make up the choice alternatives, and the model predicts the probability that each of the routes in the set will be chosen. In this class of models, simple multinomial logit models are the simplest and perhaps most commonly used. However, the IIA (independence from irrelevant alternatives) property of the simple logit model restricts its applicability to general route choice analysis. This property results from the logit model assumption that path utilities include a random error term, and that the error terms of different paths are statistically independent of each other. Particularly in urban road networks, where alternative paths may overlap over significant portions of their length, the IIA property can be violated because of correlations in unobserved path attributes.

A number of modifications to the basic multinomial logit specification have been proposed to address this problem. For example, a size variable or a commonality factor may be included in the utility function to account for overlap between paths in the choice set. Another approach is the scaled paired combinatorial logit model, which scales the path utilities by a pair-wise similarity parameter. These models retain much of the simplicity and computational convenience of the basic logit model form, but overcome the unrealistic consequences the IIA property by coping with the correlation between paths.

The nested logit model, a generalization of the simple logit model, has also been used for route choice modeling. The advantage the nested logit model is that, by construction, it avoids the IIA property of the standard logit model. Estimation of nested logit models is only slightly more complex than that of simple logit models; software is readily available for this purpose.

Application of discrete choice modeling methods to route choice behavior is made complicated by the very large number of practically feasible routes between most origin and destinations, and the complex overlapping of these routes. The paper by (Ben-Akiva, Bergman et al. 1984) treats these difficulties by developing a two-stage model structure: choice set generation followed by selection from the choice set.

In the first stage, a labeling approach is used to reduce the huge number of potential routes to a much smaller number of routes, each of which reflects a criterion that might be relevant to route choice. These criteria (minimize time, minimize distance, maximize scenery along routes, etc.) are called labels. For each label, a criterion (or a generalized impedance) function is defined so that a network minimum path algorithm can be used to build trees that are minimal with respect to the criterion. Paths in these trees emphasize the corresponding label characteristics. For example, when considering the scenery label, time spent on roads with poor scenery would be weighted much more heavily (i.e., have greater impedance) than time on scenic roads. In specifying and selecting these labels, the objective is to generate a reasonable set of paths that include the actual paths chosen by the drivers. The selection of labels is made to maximize the coverage by the label set of the actually chosen paths, and the optimal values of the parameters of the impedance functions are the values that maximize this coverage. A deterministic choice set generation model is estimated for this purpose.

In the second stage, a model of choice from the set of labels is applied to predict the chosen route. A discrete choice model in the form of nested logit model is used for this stage. Path attributes specified in the utility function include generic variables like time and distance that describe the physical path, as well as dummy variables. The resulting model formulation was too complicated to be estimated using available software. Estimations were made with a series of successively less severe restrictions imposed on the general model.

In the study of individual route choice behavior, it is important to capture the heterogeneity in drivers' tastes (preferences). In general, taste variations across individuals results in differences regarding their responses to alternative attributes and their preference to various choices. Similarly, when studying the behavior of an individual over time (because of repeated surveys, for example, or when modeling a learning process), it is important to recognize potential correlations between the individual's choices. A logit model with fixed coefficients is not capable of fully accounting either for the variations in taste between individuals or the correlation between repeated choices by the same individual over time. Accurate modeling of route choice behavior requires a model that can capture differences in intrinsic preferences and subjective evaluation of alternative attributes due to both observed and unobserved heterogeneity.

The mixed multinomial logit (MML) model provides the flexibility to cope with these issues. In the MML model, an additional error term is added to the utility specification. Depending on the model, the additional error term may have a normal, uniform, log-normal or other distribution, with parameters to be estimated. The additional term captures heteroscedasticity among individuals and allows correlation over alternatives and time. However, this generality comes at a cost: choice probabilities cannot be computed analytically as they can, for example, in a logit model. Simulation techniques must be used to approximate the choice probabilities needed for model estimation and application. Recent advances in simulation-based estimation procedures make this more computationally feasible than it formerly was.

(Han, Algers et al. 2001) used an MML formulation to model route choice. Different error term distributions and model specifications were tested. The models with log-normal error distributions could not be estimated due to computational difficulties, leaving three alternative distributions – fixed, normal, and uniform. The logit model tested with fixed coefficient values differs from the standard logit model by incorporating the correlation between repeated choices by an individual. Dramatic improvement in the statistical performance of the models was found by allowing the coefficients of observed variables to vary randomly across individuals. The change in the estimated parameters caused by using the MML model was also significant. Parameter coefficients are generally larger in the MML relative to the simple logit model.

2.2 Departure time choice

Peak period congestion is one of the most persistent problems facing the transportation system. Transportation planners and transit operators have become increasingly aware of the need to spread the concentration of peak period travel. Various strategies proposed to combat the peak period problem are based on encouraging commuters to alter the time at which they travel to work. One way of assessing the potential impact of these strategies is to develop an understanding of the factors that affect commuters' departure time decisions. A significant amount of research has been done on modeling commuters' departure time choice in the absence of information.

A number of research papers on this topic have been reviewed. Again, given the amount of published research and the limited time frame available for the literature review, this cannot be considered a comprehensive survey of available material; rather, it highlights a number of interesting and representative research efforts and their conclusions.

Many research efforts apply disaggregate random utility models, of which the simple multinomial logit model is perhaps the most widely used. In the context of departure time choice modeling, discrete departure time intervals are used as the choice alternatives.

Departure time was modeled in combination with mode choice by (Hendrickson and Plank 1984): mode and departure time choices were treated as a simultaneous interactive decision. They developed a logit model that included up to twenty-eight alternatives, representing combinations of four modes (drive alone auto, shared ride, transit with walk access and transit with auto access) and seven different departure time intervals of 10 minutes each. The modal utility specification included: free flow in-vehicle travel time, the portion of total travel time due to congestion; monetary cost divided by income; walking time on the home end of a transit trip; wait time; minutes of late arrival at work and a quadratic function of that; minutes of early arrival at work and a quadratic function of that.

Much departure time research has focused on auto commuters; transit users have been neglected from consideration. One exception is a discrete choice modeling study by (Abkowitz 1981) of departure time choice. Among the objectives of this research were to extend the study of commuter departure time to include transit commuters, to include consideration of a wide range of socio-demographic characteristics, to account properly for the travel time uncertainty in departure time choices, and to improve the definition of arrival measures. Departure time choice was modeled conditional on mode choice. Departure time was represented as a discrete choice, using a logit model formulation. Each alternative represented a five-minute departure time interval, and the data input for each alternative represented an average of departure attributes for the interval. It was assumed that transit service frequency was sufficiently high during the peak period that all transit users were given a full set of choices.

Although the multinomial logit model structure is appealing to researchers because of its simple formulation, its IIA property is not always appropriate. In the context of departure time modeling, the IIA property implies that that the comparison of two departure time intervals does not need to consider whether they are adjacent or non-adjacent. In reality, two adjacent intervals are likely to be perceived similarly due to unobserved attributes common to both.

The ordered generalized extreme value (OGEV) structure generalizes the MNL structure by allowing an increased degree of sensitivity between adjacent departure time alternatives compared to between non-adjacent departure time alternatives and avoids the IIA restriction. (Steed and Bhat 2000) attempted to model departure time choice using an OGEV structure. However, the dissimilarity parameter in the OGEV model was greater than 1, implying inconsistency with utility-maximization theory. Hence, only the MNL structure was used for the analysis.

The argument in support of the treatment of departure time as a discrete choice is that travelers can only distinguish among a few prevailing traffic conditions over a specified departure period. However, discretizing departure time imposes an arbitrary structure of time intervals on the decision model. (Abu-Eisheh and Mannering 1987) develop and estimate a model that treats departure time as continuous variable and thereby avoids any *a priori* restrictions due to time discretization. Departure time is modeled as a function of the work start time, travel time, work access time and delay cushion (defined as the time difference between work start time and arrival time). Work start and work arrival times are assumed to be exogenous to the route and departure time choices. Travel time on a route is modeled as a function of route specific characteristics, commuter socio-economic characteristics and vehicle characteristics. However, since travel time on a route and the route choice are interrelated, there is a selectivity bias. The expected value method is used to correct this problem, where every route specific variable included in the travel time equation is replaced by its expected value. Delay cushion on a route is also modeled as a function of route specific characteristics, commuter socio-economic characteristics and commuter preferences for early or late arrival. The delay cushion model is also corrected for possible selectivity bias. The travel time and the delay cushion models are estimated by ordinary least squares.

Another approach to departure time modeling uses Poisson regression. The motivation for this is the belief that commuters never completely settle on a fixed departure time and route because they continually experiment with travel options and because of random effects such as weather. Within this context, a Poisson distribution is found to be a reasonable description of the number of departure time changes. Such a methodological approach is commonly referred to as Poisson regression. (Mannering 1989) and (Jou and Mahmassani 1994) used this approach to model the number of departure time changes by commuters within a month and a week respectively.

A novel approach to model driver departure time decisions is to investigate the cognitive aspects of the decision. This approach treats the departure time choice as a problem of decision-making problem under uncertainty. It criticizes the expected utility theory approach that is frequently applied to departure time modeling because expected utility theory is felt to ignore the cognitive processes underlying observed travel behavior. Depiction of travel behavior under uncertainty requires cognitive models, rather than probability theory, to capture the mental representation of uncertainty. Another finding of this kind of approach is that the decision frame, i.e. the subjective interpretation of the decision problem, critically affects decision-making. It has also been pointed out that the uncertainty of outcome is perceived as an interval of possible resultant values. Based on these findings from cognitive science, (Fujii and Kitamura 2001) propose a model of commuter departure time choice based on a cognitive task and a mental representation of uncertain travel time. By using departure time choice data, the study shows the presence of decisional phenomena, which are poorly explained by expected utility theory, but are explained well by the proposed model.

Most of the research on departure time modeling considers peak period work trips exclusively. In contrast, (Steed and Bhat 2000) modeled departure time choices for home-based recreational and shopping trips. This research examines the effect of socio-demographic characteristics, employment-related attributes, and trip characteristics on individuals' departure time choices. The departure time alternatives are represented by several temporally contiguous discrete time periods such as early morning, a.m. peak, a.m. off-peak, p.m. off-peak, p.m. peak, evening. The choice among these alternatives is modeled using a discrete choice model. Two alternative discrete choice structures were explored. The first is the multinomial logit (MNL) structure and the second is an ordered generalized extreme value (OGEV) structure.

2.3 Mode choice

The literature on mode choice modeling is vast, and no attempt was made to review or summarize it. The following paragraphs simply note some modeling approaches commonly applied.

As travel modes are by their nature discrete alternatives, discrete choice models suggest themselves as a natural modeling approach. In this approach, all the modes available to a traveler constitute the choice set. Simple logit models are often applied to compute the probability of choosing each mode. The utility to a traveler for a particular mode can be a function of travel time (in-vehicle and out-of-vehicle) on that mode, out-of-pocket costs on that mode, perceived costs on the mode, socio-economic and demographic characteristics of traveler, workplace dummy and lots of other dummy and continuous variables. Many of these variables can be specified either generically or as specific to one alternative.

As has been mentioned above, the standard logit model has the independence from irrelevant alternatives (IIA) property. This means that for a specific individual the ratio of the choice probabilities of any two alternatives is entirely unaffected by the systematic utility of any other alternative. This can be unrealistic in mode choice modeling, because some modes in the choice set may have similar unobserved attributes and so have correlated utilities. An individual choosing between auto, commuter rail and express bus, for example, is likely to have somewhat similar (positive and/or negative) feelings about bus and rail, so treating them as completely independent vis-à-vis the auto could lead to unrealistic choice predictions.

The simplest generalization of the logit model that avoids this problem is the nested logit model; properly specified, it does not suffer from the IIA property. In this modeling approach, alternative modes that are likely to have unobserved common attributes should be put in a single nest and the resulting model should be used. The model incorporates a higher-level choice between nests, and a lower-level choice among the alternatives in a nest. In the previous example, it would be reasonable to group the commuter rail and express bus in a single "commuter transit" nest. The high-level choice would be between auto and commuter transit, with a lower-level choice between bus and rail in the transit nest.

3 TRAVELER BEHAVIOR WITH INFORMATION

This section considers the question of traveler behavior in the presence of real-time travel information.

This general question actually involves a number of closely inter-related sub-questions:

- which kinds of travelers would use real-time travel information if it were available? What kinds of trips would they want to use it for?
- how would they respond to the information once they received it? How would directly affect decisions about a trip being contemplated or made? How would it affect the context in which trips are made?
- what specific types of information would these travelers want to access?
- how much would they be willing to pay to receive the information?
- what would be their assessment of the benefits they received from accessing the real-time travel information and responding to it?

- how would this assessment of their experience affect the answers to all these questions the next time they have the opportunity to use it?

Because of their deep interdependence, all these questions should ideally, perhaps, be addressed and answered simultaneously. However, it is necessary to begin somewhere. Therefore, this section starts with a review of some of the literature that analyzes and characterizes the potential users of ATIS. From this, it turns to examine the various kinds of user response to travel information that have been studied. It then looks at users' preferences and willingness to pay for different types of information. There follows a discussion of the dynamic effects that can occur when day-to-day learning behavior is considered. Finally, a number of specific topics in traveler response data collection, analysis and modeling are discussed.

3.1 Who are the potential users of real-time travel information?

Understanding who are the potential users of advanced travel information services is essential both for designing and marketing those services and for predicting the users' responses to them. It is intuitively clear that ATIS can serve a variety of different kinds of users, and that these different kinds of users may react to ATIS messages in substantially different ways. The better these differences are understood, the better user needs can be met and user response can be predicted.

Studies of travel behavior are increasingly drawing on ideas and methods of market research. These methods typically attempt to identify subgroups ("segments") of the total market having the property that individuals within a subgroup share many similarities with respect to variables of interest in a study (e.g., travel behavior, socio-economic characteristics), and individuals in different subgroups differ significantly along these dimensions. Each homogeneous market segment can be more efficiently studied than can the mixed population as a whole.

A straightforward way of implementing these ideas is to identify segments on the basis of the exhibited behavior of interest (e.g., ATIS users), and to correlate membership in the segment with other measurable characteristics (e.g., socio-economic characteristics). Although useful, this approach has the disadvantage of being able to identify only relatively simple correlations, and perhaps also of reflecting the analyst's a priori beliefs and preventing a more exhaustive exploitation of the data.

More sophisticated market research methods such as cluster analysis can statistically identify population subgroups whose members share high degrees of similarity across many dimensions. While outputs of statistical procedures always need to be interpreted with insight and caution, clustering methods are often capable of identifying previously unknown significant population segments that might not have otherwise been recognized in the data.

Factor analysis is another method of identifying structure in a data set consisting of multiple observations, each one involving multiple variables of interest. Factor analysis identifies sets of linear combinations of the variables that distinguish as much as possible among the observations. Given a particular linear combination of variables (a *factor*), an observation's *score* with respect to the factor is the numerical value of the linear combination evaluated using the particular values of the observation's variables. Factor analysis identifies factors such that (i) the distribution of scores with respect to each one has maximum variance (i.e., the factors have maximum discriminatory power), and (ii) different factors are orthogonal to (i.e., uncorrelated with) each other. When a factor's linear combination includes some variables with very high coefficients and others with very low coefficients, its interpretation may be relatively easy. Factors involving more general linear combinations with arbitrary coefficients on the variable may be more difficult to interpret. In such cases, identified factors may subsequently be "rotated" to facilitate their interpretation in terms of specific variables or sets of variables, and this rotation may introduce correlations between them.

The combination of factor and cluster analysis is a particularly powerful means of identifying market segments, and has come to be a standard method in market research. Factor analysis is first applied to a data set of survey results to identify a set of factors that efficiently and parsimoniously distinguishes the observations. Each observation's scores with respect to the different factors are computed, and then cluster analysis is applied to identify subgroups of observations having similar factor scores. It remains for the analyst to impose a meaningful interpretation of the subgroups so obtained.

(Proussaloglou, Haskell et al. 2001) describe an application of combined factor and cluster analysis to identify transit user market segments in the San Diego metropolitan area. They then develop (fairly conventional) transit mode choice models for each distinct market segment.

Turning to analyses of the potential market for ATIS services, most surveys of potential ATIS users have carried out simple correlations or other descriptive analyses of stated use propensity with socio-economic or characteristics. Work pursued over a number of years by a group at the University of Washington (Barfield, Haselkorn et al. 1989; Haselkorn, Spyridakis et al. 1989; Haselkorn, Barfield et al. 1990; Wenger, Spyridakis et al. 1990; Spyridakis, Barfield et al. 1991; Conquest, Spyridakis et al. 1993) is among the first examples of the application of cluster analysis techniques to investigate the characteristics of potential ATIS users. Based on an mail-in driver survey and follow up personal interviews, the researchers were interested in the respondents' use of traffic information (commercial radio and TV traffic reports, HAR, VMS) and response to it, and in the influences that affect these responses. Cluster analysis of the survey results was intended to identify subgroups that differ significantly in their use of traffic information. The four groups identified by the cluster analysis were (in decreasing order of frequency in the sample): departure time and route changers; non-changers; route changers; and pre-trip changers. (Although mode change behavior in response to travel information was also investigated, the number of respondents who reacted to travel information by changing mode was not significant.) Descriptive statistical analysis was then used to further characterize each of the identified market segments in terms of its use of and attitudes towards different information sources; its priorities with respect to different information features; its tripmaking and activity constraints; and its demographics.

(Mehndiratta, Kemp et al. 1999b) (see also (Mehndiratta, Kemp et al. 2000; Mehndiratta, Peirce et al. 2000)) illustrate the application of combined factor and cluster analysis techniques, as described above, to delineate distinct segments of ATIS users. A detailed collection of data on travel behavior including use of travel information was conducted as part of the ongoing Puget Sound Regional Council's travel diary panel survey. The survey included conventional demographic and socio-economic information as well as responses to attitudinal questions. From this data, individuals with a high propensity to use travel information were identified. An initial attempt to correlate membership in this group with socio-economic characteristics, based on stereotypes of expected users types (e.g., road warriors, commuting mothers) proved only partially successful. Accordingly, a factor analysis of the entire survey population’s attitudinal question responses was performed, and a cluster analysis using the factor scores was carried out to identify distinct segments. Although the segments were defined uniquely in terms of their attitudes, subsequent analysis showed that the segments also differed with respect to their travel behavior, demographic profile, and propensity to use ATIS. The incidence in each segment of individuals likely to use ATIS was then determined.

Eight distinct market segments were identified through the combined factor/cluster analysis. The segments with higher-than-average incidence of ATIS users were termed:

- control seekers: people who travel a lot, are comfortable with technology, like to plan ahead but are not set in their ways;

- web heads: people who are interested in cutting-edge technology and traffic information, although they are less interested in portable electronics.

- rigid routines: people who usually follow the same routine but listen to traffic information and will make small adjustments to their trips;

- value-added service buyers: people uncomfortable with maps and computers who appreciate things that facilitate their daily lives;

- wired with children: people with high incomes, long commutes and children, for whom convenience is important.

Subsequent application of this approach to a wider sample of people who had used ATIS during the various MMDI programs revealed an additional potentially important segment:

- mellow techies: people with little interest in traffic conditions or trip planning, and little concern about being late, but who have high levels of internet and computer use.

It is clear that application of techniques such as these can provide considerable insight into the structure of the market for ATIS services, and allow much more focused investigation of the characteristics, system preferences and behavioral responses of potential ATIS users.

3.2 Traveler response to real-time information

(Polydoropoulou and Ben-Akiva 1999) have described a number of successive stages that travelers typically go through before they become regular ATIS users. These are:

- awareness, where the traveler begins to have basic information about the availability and attributes of a travel information system;

- consideration set formation, where the traveler generally begins to think of ATIS as a possible option to consider before making trips;

- choice set formation, where ATIS is definitely included as an option to assess in response to a specific identified travel need;

- trial use, where the traveler decides to try ATIS to gain more familiarity with its characteristics and potential benefits and costs;

- repeat use, where ATIS is assimilated into a traveler's continued or habitual travel behavior, although further experience may cause the continued use to be reconsidered.

At the point where repeat usage becomes established, it becomes possible to speak of a systematic traveler response to real-time information. These responses are divided here into two general categories: those involving the tripmaking context, and those involving tripmaking itself. The sections below discuss these responses, drawing on the literature review to indicate the extent of current qualitative and quantitative knowledge about the responses.

Responses to ATIS involving the tripmaking context include behavior that affects the way that trips are scheduled or integrated into daily activities. These include adjustments to residential and/or employment location decisions; adjustments to daily activity schedules; changes in habitual tripmaking behavior; effects on non-travel activities; and trip-related stress or anxiety relief.

Responses to ATIS involving tripmaking itself cover a wide range of trip-related decisions: the decision to travel or not; the choice of destination or destinations (trip chaining); choice of departure time, mode and route; the re-routing decision in response to an incident; driving behavior; and the choice of parking location.

These various possible responses are discussed individually below, despite the fact that in many cases the responses are inter-related. The discussion also examines a number of specific examples of traveler response that merit separate consideration; these include ATIS impacts on shopping trips, transit information systems, variable message signs, and driver compliance with prescriptive information.

It will be seen that, in most cases, very little quantitative information is available. The available information tends to be highly specific to particular situations; very few quantitative conclusions of a generally applicable nature can yet be drawn regarding user responses to ATIS. This is not entirely surprising: significantly research into and deployment of ATIS has only been taking place for the past decade or so. Highways and transit systems were in use for many decades before generally reliable data and models on traveler response to them began to be developed. The pace of research and investigation is faster now, and the methods of data collection and analysis more efficient and sophisticated. Still, the current state of knowledge provides at best general qualitative conclusions regarding traveler response to ATIS. More deployments, more experience with deployed systems, and more research and analysis will be required to move ahead.

3.2.1 TRIP CONTEXT RESPONSES TO ATIS

3.2.1.1 Reduce stress and anxiety

Many surveys have found that tripmakers appreciate having travel information available even if they do not or cannot modify their tripmaking behavior in any way because of it. Some analysts see this reaction as similar to peoples' appreciation of weather forecasts. Respondents typically claim that the information reduces the level of anxiety or stress associated with not knowing what travel conditions are going to be. (Khattak, Schofer et al. 1995) and (Khattak, Yim et al. 1999), for example, discuss survey results where users mention this reaction.

(Lee 2000) has attempted to make the notion of travel stress relief more precise by arguing that the value of time spent in travel includes at least two distinct components: the opportunity cost of the activities foregone by traveling, and the disutility of the travel experience itself. This disutility is likely to be higher when a lack of information about travel conditions ahead causes one to be anxious or under stress; conversely, receiving travel information may make one more "serene" during a trip. The value of time spent traveling is likely to be higher in the former case than in the latter, and the benefit of the stress-relieving impacts of ATIS can be estimated as a function of the difference in value of time and the total time spent traveling.

3.2.1.2 Affect non-travel activities at the trip endpoints

Travel information may enable tripmakers to beneficially adjust the activities that they undertake at the departure or arrival ends of a trip. A person stuck in traffic may be able to call ahead with an accurate arrival time estimate and, before arriving, re-arrange her schedule at the destination to minimize the impacts of the delay on other activities. A person who wants to complete a task at one location but also needs to arrive at another location on time may be able to make use of accurate travel time information to determine if there is sufficient time to complete the task before departing. In the absence of such information, the person may abandon the task even if there was enough time to complete it; or complete it, and arrive late at the next location.

A Mitretek study ((Shah, Toppen et al. 2001; Wunderlich, Hardy et al. 2001); see also (Shah, Wunderlich et al. 2001)) provides evidence from simulated yoked driver experiments involving the Washington DC and Minneapolis/St. Paul metropolitan areas that pre-trip ATIS can significantly reduce the early and late schedule delays, and reduce the number of late arrivals. These studies compared the travel time and arrival time reliability of pairs of simulated drivers with identical origin, destination and desired arrival time at the destination. One driver was assumed to have access to pre-trip ATIS information on link travel times, and the other not. (The link travel time information was empirical data, compiled by polling an on-line traffic information service for conditions at five-minute intervals over a large number of days.) Drivers without access to information were assumed to base their path and departure time choices on average link conditions experienced over time, while those with access were assumed to utilize the "real-time" (but non-predictive) link times to make these decisions. In each case, the consequences of the decisions, in terms of travel and arrival time, were determined by reference to the compiled data on actual link times. (Compiled values were slightly perturbed to account for the variability in the time estimates.)

The study found that pre-trip information had only a minor effect on the average travel times experienced by its users. However, ATIS users reduced their number of late arrivals by 62%, and the total late schedule delay by 72%. (These benefits varied significantly by time of day.) The conclusion is that pre-trip ATIS is likely to impact travel time reliability much more than travel time itself. The study also suggests that, in the travel contexts considered, pre-trip ATIS is more likely to produce departure time changes than path choice changes.

3.2.1.3 Adjust daily activity schedule

People schedule the activities that they need to accomplish in a day based in part on the time taken by each activity and the time required to travel between activities in different locations. Because of uncertainty about travel times, people tend to incorporate "slack" in their scheduling decisions to reduce the risk of schedule disruptions due to worse-than-expected travel conditions.

Reliable information on travel times and traffic conditions will allow people to eliminate some of this slack. The time freed up in this way could be used in a wide variety of ways. At one extreme, it could be used to sleep or relax more; at the other, it could lead to a significantly different organization of the day's activities including new activities and shifts in the order of activities. In terms of tripmaking, the additional time could lead to new trips, to trips made at different times, or to trip chaining.

Although these kinds of behavioral adjustment are entirely plausible, there is as yet very little evidence that they have occurred among users of currently-deployed ATIS.

3.2.1.4 Adjust habitual tripmaking behavior

There is considerable evidence that tripmakers rely to a large extent on habit when making their travel decisions. Over time, they establish a set of default behaviors that influence their tripmaking behavior on particular trips. These default or habitual behaviors do not necessarily dominate the decision-making process; rather, their effect is to increase the likelihood that, in any particular decision context, the default choice will be made. (Aarts, Verplanken et al. 1997) provide an analysis of bicycle use by students that supports this view.

(Uchida, Iida et al. 1994) surveyed commuters in a three-route corridor in Osaka, Japan following the installation of a VMS network that provided predicted travel time information. They identified two types of response to the information:

- tactical response, meaning the immediate decision to divert or not based on reported travel times for the three routes; and

- strategic response, the change over time in drivers' selection of their habitual route.

The VMS was found to significantly affect both types of response. However, decision inertia was also found to be important in both. In the case of the tactical response, drivers showed a reluctance to switch away from their habitual route, other things being equal. In the case of the strategic response, drivers were reluctant to change their habitual route, even when the VMS repeatedly showed it to be an inferior alternative.

(van Berkum and van der Mede 1998) present a sophisticated modeling and analysis framework that accounts for the effects of ATIS in immediate travel decision-making and longer-term habit formation and change. The article presents empirical results that support their framework and highlight the importance of habit in tripmaking behavior. Similar results are presented, in another problem situation, in (van Berkum and van der Mede 1999).

One potentially important factor not considered in these studies is the possible effect of ATIS-produced changes in the daily activity pattern on the formation of travel habits. If, as was discussed in the preceding section, accurate travel condition information from an ATIS leads to a reorganization of a persons' daily activity pattern, it is probable that habitual travel behavior will also change as a result.

3.2.1.5 Adjust residence and/or employment location

The variety of changes brought about by ATIS in the tripmaking context could lead people to reconsider their decisions regarding residential and/or employment location. As one example, if more predictable travel times became available from an ATIS, households could move farther away from job locations while still maintaining the same average commute time. Again, rearrangements in daily activity schedules brought about by ATIS could allow more time for outdoor activities, and incite households to take advantage of this by moving. Through these kinds of effect, ATIS could ultimately have an impact on urban form and structure. (Boyce 1988), in an early paper, evoked this possibility. (Hamerslag and van Berkum 1991) presented a simple network model that exhibits such location decision effects. However, it is likely that ATIS deployment on a much larger scale than today's will be required before such effects become noticeable or significant.

3.2.2 TRIPMAKING RESPONSES TO ATIS

3.2.2.1 Decision to travel or not

Relatively little information is available regarding the effects of ATIS on the decision to travel or not; however, it is not inconceivable that information about sufficiently bad travel conditions could induce tripmakers to cancel their intended trips, particularly discretionary trips.

(Khattak, Yim et al. 1999) cite evidence for this effect from CATI and mail questionnaire surveys carried out as part of the San Francisco-area TravInfo project. The surveys covered automobile and transit travelers and commute and non-commute (e.g., shopping or personal) home-based trips. The surveys asked respondents about the effects of pre-trip travel information (available from television, radio or telephone sources) on their tripmaking decisions. Analysis of the survey results revealed a number of general aspects of traveler response to the available information sources, some of which are discussed in sections below.

One of the findings was that non-commuters would occasionally decide to cancel their (presumably discretionary) trips because of unfavorable travel conditions reported by the various information sources, and particularly by radio. It is widely agreed that the demand for non-commuting trips is relatively elastic with respect to travel times and costs – in other words, an increase in travel times or costs leads to a reduction in tripmaking. In view of this, it is not surprising that information about bad travel conditions would lead, at the individual level, to non-commute trips being canceled. However, this is the only empirical evidence that was encountered in the literature review for such an effect.

3.2.2.2 Choice of destination or destinations

Similarly, relatively little information is available in the literature regarding the effects of ATIS on destination choice, or on the decision to visit several destinations and accomplish several purposes in one trip through trip chaining. Trips offering a choice of destination alternatives are likely to be for shopping or personal purposes, rather than for commuting. The opportunities to group multiple purposes and destinations into a trip chain are more varied and difficult to characterize and analyze.

The effects of ATIS on shopping trip destination choice was investigated in a set of internet-based stated preference surveys by (Kraan, Mahmassani et al. 2000) and (Mahmassani, Huynh et al. 2001). In the survey, respondents were asked to make a (simulated) shopping trip from a central location in Austin, Texas to a major suburban mall. Different pre-trip and en route messages about travel conditions were provided in the course of the decision-making process. Following notification of a change in traffic conditions while en route, the respondent was given the options of continuing on the same route; continuing to the same mall but via a different route; or switching to a different shopping mall entirely. Appropriate information was provided in each case. A sequential decision framework was developed to capture the conditional nature of the choices. It was found that the decision to switch route or destination was not influenced by age, gender, education and income. Respondents who were less familiar with the Austin area were more likely to switch destination, but not route. Those who visit the same mall on a frequent basis were less likely to switch destination and route. In general, switching response was greatest when information on traffic delays (as opposed to other kinds of traffic data) was presented.

Again, these are the only references located during the literature search on the topic of destination choice and trip chaining impacts of ATIS. Indeed, these questions are not well covered in the broader transportation literature; data on trip chaining, in particular, is difficult to collect and analyze.

3.2.2.3 Departure time choice

Departure time and route choice are often considered together in discussions of travel behavior. Many surveys of pre-trip user behavior collect data on both types of decision. They are considered separately in this discussion of ATIS because route choice can potentially be influenced by both pre-trip and en route information, whereas departure time choice is by its nature a pre-trip decision only.

There are a number of indicative data elements regarding the influence of ATIS on departure time choice but, again, the available data is not complete enough to draw broadly general conclusions or to develop widely applicable models.

An early study of commuting behavior (Mahmassani and Chang 1985; Mahmassani and Chang 1986) gave some indication of the slack that commuters feel they need to build into their departure times. Around 40% of survey respondents stated that they schedule their commute trip to arrive at work at least 15 minutes before the official start time; furthermore, the early schedule delay was found to increase with increasing distance from work. This suggests that travel time variability influences the departure time decision, and that commuters leave their homes early in order to reduce the risk of late arrival from longer-than-expected travel times.

(Barfield, Haselkorn et al. 1989) (Haselkorn, Barfield et al. 1990) (Mannering, Kim et al. 1994) discuss results of surveys of Seattle-area commuters who receive travel information from radio, television and telephone services. Of the commuters surveyed, 40% indicated that they had some flexibility in scheduling and selecting the route for their morning commute trip; 23% indicated no flexibility. However, 64% responded that they rarely changed their departure time because of pre-trip information.

(Khattak, Schofer et al. 1991) and (Khattak, Yim et al. 1999) report that the perceived accuracy of pre-trip reports is important in determining whether commuters take account of it in their decision-making. The importance of perceived pre-trip accuracy was also reported by (Polydoropoulou and Ben-Akiva 1999) based on analyses of San Francisco commuter surveys.

(Srinivasan and Mahmassani 2001) investigated using travel choice simulators the mechanisms by which drivers arrive at a departure time decision based on ATIS messages. They hypothesized that a driver undertakes a sequence of decisions to arrive at an adjustment to her habitual departure time. First, the driver decides whether or not to adjust the habitual departure time. Conditional on the decision to adjust, departure time alternatives are evaluated sequentially in about five minute increments. The directionality of adjustment (i.e., towards earlier or later departure) is governed largely by the direction of schedule delay experienced on the preceding day, with an earlier switch following prior lateness and vice versa. The results illustrate that the observed departure time adjustment behavior is influenced by dynamic transportation system attributes encountered such as trip time variability in the network, trip-makers' short and longer term experiences, and the nature, type and quality of real-time information supplied by the ATIS.

3.2.2.4 Mode choice

Relatively little detailed information is available about the mode choice impacts of ATIS, although there is some evidence for this effect.

As reported in (Yim and Miller 2000), less than 1% of the early callers to San Francisco's Travinfo service asked to be rerouted to the transit menu after learning about bad traffic conditions from the traffic menu. However, as experience with the system increased over the duration of the Travinfo field test deployment, it was found that up to 5% of the callers asked to be rerouted to the transit menu, a significant increase. Of those who accessed transit information, 90% of them chose transit for their travel mode. (Of course, a large fraction of the callers probably consisted of habitual transit users; it cannot be concluded that the information that they received caused them to choose transit.)

(Polydoropoulou and Ben-Akiva 1999) (see also Khattak, Polydoropoulou et al. 1996) discuss an analysis of San Francisco data that showed that prescriptive recommendations to take public transport have a detectible effect on mode choice, particularly in situations of unexpected delay.

3.2.2.5 Route choice

Many surveys and travel choice simulator studies have demonstrated the ability of ATIS to influence route choice. (Khattak, Yim et al. 1999), for example, presented survey results in which over 50% of respondents reported that they had made travel route or departure time changes in response to pre-trip information received by radio, television or telephone. (Owens 1980) describes an early travel choice simulator study that demonstrated drivers' willingness to divert in response to highway advisory radio (HAR) messages about incidents. Some researchers have estimated sophisticated econometric models of route choice or route switching probabilities in response to ATIS, for example (Uchida, Iida et al. 1994) and (Polydoropoulou and Ben-Akiva 1999).

However, as stated above, from these various surveys and modeling efforts it is difficult to extract generally applicable quantitative conclusions regarding traveler response to information. The state of knowledge does not yet allow the development of a general model capable of predicting that, on a given network, X% of drivers will divert to route Y if they receive message Z while driving. Unfortunately, sufficient experience with and data about these systems is still lacking. Accordingly, this section will focus on qualitative conclusions that have been obtained from the various analysis efforts that were alluded to above.

Based on analysis of driver route choice responses to both VMS and radio information, (Emmerink, Nijkamp et al. 1996) have suggested that some people have a natural propensity to use traffic information of any kind and from any source. (See the discussion in Section 3.1

above.) Nonetheless, there is considerable evidence that the nature of the guidance information, and the conditions experienced prior to its dissemination, can strongly affect driver route choice response to it.

(Khattak, Schofer et al. 1995) and others have found that drivers tend to prefer messages that are descriptive (information about traffic conditions) rather than prescriptive (route recommendations). They found in particular that drivers are most receptive to near term predictions of traffic conditions on congested routes with rapidly changing conditions.

However, drivers' perception of the accuracy and reliability of the messages is a key determinant of their response. (Kantowitz, Hanowski et al. 1997a; Kantowitz, Hanowski et al. 1997b) have found that there exists an accuracy "threshold", beneath which drivers will simply ignore ATIS messages. Factors that increase drivers' confidence in the accuracy of the messages tend to increase the likelihood that the drivers will react to them. In the context of route choice, such factors include a driver's own observation of congestion prior (and particularly just prior) to receiving the message, and favorable experiences with the ATIS in prior uses.

Prescriptive messages do generally have an effect on route choice, as shown in many travel choice simulator studies and surveys of driver behavior. Combining a prescriptive recommendation to change routes with descriptive information justifying the recommendation has been found in travel choice simulator experiments to result in the highest route switching compliance rates. More generally, (Polydoropoulou and Ben-Akiva 1999) found that, in en route switching situations, the switching rate increased with the elaborateness (level of detail, care in justification) of the guidance messages.

(Owens 1980) found that drivers who received prescriptive information about incident diversion routes were generally more successful in avoiding the incident than those who received descriptive messages only. The success of the latter drivers depended strongly on their knowledge of the network around the incident. However, he found that the travel costs incurred by the two sets of drivers in diverting were not notably different.

(Llaneras and Lerner 2000) also investigated the ability of drivers to translate guidance messages into effective route choices. They considered "simple" and "enhanced" in-vehicle ATIS capabilities; the latter provided basic descriptive and qualitative information on incidents and congestion, while the latter provided the simple information as well as details about incidents, alternate routes, and real-time congestion conditions as well. Overall, drivers were able to use both types of system to divert around incidents. However, he also found that drivers sometimes made incorrect route choices with both types of system. The prevalence of these errors was significantly higher with the basic system; furthermore, the mistakes made with that system were generally more costly (in terms of excess delays) than those made with the enhanced system.

A number of generally idiosyncratic factors also condition a driver's route choice response to ATIS messages. A freeway bias has been observed in several studies ((Hato, Taniguchi et al. 1995; Kitamura, Jovanis et al. 1999)). Because of this bias, drivers receiving messages that suggest diverting from a non-freeway to a freeway facility are considerably more likely to switch than drivers who receive the opposite message, other things being equal.

The influence of habit or inertia on route choice response has also been noted in a number of studies ((Uchida, Iida et al. 1994) (Hato, Taniguchi et al. 1995) (Srinivasan and Mahmassani 2000b)). Drivers tend over time to establish a preferred route for particular trips. Guidance messages that suggest switching from the preferred route to another are less likely to be accepted than messages that suggest the opposite. Of course, habit does not always over-rule information received from guidance messages. A sufficiently strong message, corroborated by the driver's observations and confidence in the ATIS, will be considered. Over time, the effect of ATIS may be not only to affect particular route choice and switching decisions, but in fact to change the habitual route choices themselves.

3.2.2.6 Incident diversion response

A special case of the route choice decision occurs when a driver becomes aware, during the trip, of an incident affecting traffic conditions on the path currently being followed. Incident-related and other non-recurrent congestion is a major contributor to total congestion delays on highway networks; for example, it has been estimated that roughly half of all delays on freeways in the U.S. are due to non-recurrent causes. Driver response to an incident situation determines in part the severity of its consequences. It is expected that ATIS can be of considerable help in incident situations by providing drivers with timely information about the location and characteristics of the incident and by suggesting routing alternatives in what are, by their very nature, unexpected and unfamiliar circumstances.

The two key aspects of driver incident response are: whether the driver diverts at all; and, if the driver diverted and avoided the incident, whether she returns to the original route or continues on the alternate route. In the former case, the route switch represents a temporary detour around the cause of delay; in the later, the route switch entails choosing a completely new route to follow to the destination. The choice considerations at work in these two situations may well be different.

A number of studies have examined drivers' route diversion behavior in the presence of non-recurring congestion, applying a variety of methodologies for this purpose. This is actually one of the better-studied aspects of traveler response to ATIS, perhaps because of the natural interest in applying ATIS to alleviate incident conditions.

(Khattak, Koppelman et al. 1993) investigated factors that influence auto commuters' en-route diversion propensity. Data on propensity to divert and related factors were collected through a stated preference (SP) questionnaire survey. The effects on drivers' willingness to divert of incidents and recurring congestion, real-time traffic information, driver and roadway characteristics and situational factors were investigated using conjoint measurement.

Disaggregate discrete choice models are a natural approach for investigating drivers' diversion and return choices. Multinomial logit models (MNL) and nested logit models (that remove the undesirable IIA property of MNL) are logical model forms. (Khattak, Schofer et al. 1993) examined diversion and return choices using these two forms. The model structure represents these choices as interrelated to take account of the likelihood that drivers' diversion choices will depend, in part, on their expectation that they will or will not return to the original route. That is, the driver chooses among three alternatives: no diversion (ND), diversion and no return (DNR), and diversion and return (DR). The authors used a joint multinomial logit model of the choice among these three alternatives and a nested logit model in which the return choice is nested within the diversion decision. Both these models were estimated with equivalent systematic utility function specifications; they yielded very similar coefficient values (i.e. identical behavioral interpretation). Commuters' diversion and return behavior varied with their personal characteristics and with the characteristics of the trip they were making at the time when the choice arose. Individuals making longer trips, facing longer delays and facing less expected congestion on alternate routes were more likely to divert. Commuters who made longer trips were significantly more likely to return after diversion.

(Abdel-Aty 1998) also considered alternative logit model forms to model the three diversion options (ND, DNR and DR), in an investigation of the preferred modeling structure for the incident-related routing decision. In addition to the joint multinomial logit, two nesting structures were tested. In one of them, the DR and DNR choices were modeled under a "diversion" nest, reasoning that these choices are conditional on diverting because diversion has occurred. The other specification places the ND and the DR choices under a "maintain route" nest, reasoning that the choices are conditional on staying on the same route because the majority of the route will be the same. It was concluded that the nested logit model with the ND and DR choices grouped in a nest provided the best structural fit for the observed distribution of the routing decision in case of an incident. The superiority in this application of a nested logit structure over the simple MNL form was also established.

Use of ordered categorical response data is very common in these kinds of modeling, where the bulk of the data is obtained through stated preference questionnaires. Use of multinomial logit or probit models or linear regression may lead to biases in estimation using this kind of data. (Khattak, Koppelman et al. 1993) estimated multivariate models of diversion propensity to explore the effects of several variables simultaneously. The multivariate model used was an ordered probit model with diversion propensity as a function of delay characteristics, reported trip and route attributes and socio-economic characteristics of the respondent drivers. The ordered probit model was selected for estimation because of its ability to analyze ordered categorical response data.

Another method to investigate drivers' route diversion behavior is to analyze reported and stated data about route diversion obtained through surveys. (Khattak, Kanafani et al. 1994) analyzed a survey of commuting behavior in the San Francisco Bay Area in 1993. The questionnaire was designed to use reported diversion behavior (a measure of the true behavior) as the basis of a sequence of stated preference questions about the propensity to divert with a future in-vehicle ATIS device. This methodology increases the validity of the stated preference technique by relating the response to ATIS technology to a specific behavior that was actually practiced by the respondent. The objective of the stated preference question was to determine how incremental amounts of information provided by an ATIS device would influence the propensity to divert. It appeared that respondents overstated their propensity to divert when compared with reported behavior. Around 22% of the respondents stated that they would divert even though they reported not having diverted. On the other hand, only 5% of the people stated that they would not divert even though they actually diverted when they faced the unexpected delay. To explore the correlation between reported behavior and stated preference, a linear regression model relating the answers to each question was developed.

3.2.2.7 Driving behavior

Traveler information can be used not only to improve trip-related decision-making, but also to influence driving behavior during the trip.

For example, messages might warn drivers before they arrive at hazardous road conditions (road work, accidents, bad weather) so that they drive more cautiously. (Ng and Mannering 2000) report on vehicle simulator experiments to determine the effectiveness of such advisory messages. They developed a very realistic simulation of an actual mountain road in Washington State, and included the ability to generate fog and place snowplows in the simulation. They considered the effect on driving speed of VMS messages, in-vehicle messages and both; messages warned about the presence ahead of fog, road curves, and snowplows. They found that over short distances, the messages did cause drivers to reduce their speeds; however, over longer distances there was no noticeable speed effect. This suggests that after slowing down in response to the message, drivers drove faster in order to compensate for the delay.

(Smulders 1990) describes a subtle application of this idea. He found that merely *suggesting* appropriate freeway speeds to drivers by VMS – but with no obligation on the part of the drivers to comply – had a small but noticeable effect on average travel speeds but significantly reduced the variability in these speeds across drivers on the facility. This reduction in speed variability considerably delayed the onset of the breakdown of traffic conditions at maximum flow levels, and actually increased the capacity of the freeways where the method was applied. Speed advisory VMS are now deployed on a number of freeways in the Netherlands.

3.2.2.8 Parking search and choice

Parking guidance and information (PGI) systems inform drivers about the availability of parking at various locations or recommend facilities for use.

In general, a PGI system consists of four components:

- a counting mechanism at parking facilities to track vehicle entries and exits and thus determine facility occupancy and available spaces at a given time;

- a control center that processes data on facility occupancies and generates messages about parking availability or recommendations. Messages may also include information about other attributes of parking facilities (prices, location, etc.);

- a communications network that transmits occupancy data from facilities to the control center and disseminates messages from the control center to users;

- information access technologies by which users obtain the messages generated by the control center.

The information access technology generally consists of a system of variable message signs, arranged so that traffic traveling towards the city center receives progressively more detailed data with each VMS encountered. The messages may be based either on current occupancies or on the occupancies predicted to hold at the time a vehicle passing a VMS actually arrives at the parking facility. Occupancy data may be quantitative (actual spaces available) or qualitative ("ample space", "nearly full", "full").

A number of such systems are in use in cities around the world. In some instances, both the parking facilities and the PGI system are operated by the municipal government, but this is not a requirement. In England, for example, there are arrangements where privately-operated parking facilities provide data to a PGI system run by the local government. The hardware needed to implement the system components is commercially available.

(Allen 1993) provides a useful summary of the benefits of PGI systems. These include:

- benefits to drivers by being able to proceed directly to a parking facility with available spaces, without having to spend time searching and waiting;

- benefits to traffic and environmental conditions from the elimination of parking search traffic which, according to some estimates, can be 30% or more of all traffic on roads in city centers;

- benefits from more efficient utilization of available facilities: higher occupancy levels and increased parking revenues;
- benefits from information availability about facility usage, making possible better management of the parking system (e.g., fraud monitoring, pricing policy analyses).

Many of the issues that arise in modeling general driver response to traffic-related information also occur in modeling response to parking-related information. It appears from a review of the literature, however, that parking choice and PGI systems have been less intensively investigated to date than route choice and ATIS.

Among the articles reviewed, (Teng, Falcocchio et al. 2001) surveyed parking facility users in New York City to determine the types of information they considered most useful in a PGI system, and to investigate relationships between user or trip characteristics and the ranking of information types. For a parking information web site, the information of greatest interest included fee structure, hours of operation, location, the predicted probability of having a space available at the time of arrival, and traffic conditions in the vicinity of the facility. For roadside displays, the information of greatest interest included hours of operation, number of available spaces, location and fee structure. These preferences were observed to vary by gender, trip purpose, and familiarity with parking options and conditions, among other factors. Internet-based information and in-vehicle devices were preferred to a kiosk for obtaining pre-trip information, while VMS were preferred to in-vehicle devices for obtaining en route information.

(Allen 1993) conducted stated preference surveys in an outer borough of London to investigate the effects on parking facility choice of VMS message, parking price and walk time to the destination. The survey concentrated on weekday shopping trips and distinguished three different user groups. The considered messages provided qualitative information on the occupancy of different nearby parking facilities. Two message dictionaries were considered in the SP experiments, differing most notably in that one explicitly identified facilities as "nearly full" while the other displayed a blank message for such facilities. The authors present multinomial logit model estimation results. Within the range of prices and walk times considered, the displayed message had a determining effect on parking facility choice, while price and time had secondary effects. It is not clear, however, if these conclusions would hold over a larger range of prices and times. It should also be noted that this work did not consider the practical problem of how to indicate parking facility locations to unfamiliar drivers using a VMS with very constrained message space.

The incorporation of parking choice and PGI systems in general-purpose traffic models is considered by (Chatterjee and Hounsell 1999), with specific reference to the dynamic traffic model RGCONTRAM. The authors show how parking-related movements and the associated times and costs can be represented as special links in a traffic network model. They discuss the application of a travel choice simulator to investigate joint route and parking facility choice with and without PGI messages. They describe simulator experiments that varied parking prices, expected risk of waiting to park, waiting times and PGI messages, but do not present specific model specifications and estimation results. However, regardless of the particular form of a parking choice model, it is clear from the author's discussion how an information-based traffic model (i.e., one that allows en route path diversions based on messages) could represent and integrate parking information and choice as well.

Since parking search traffic is a poorly-understood but potentially significant component of city center traffic, it would seem that further research on driver choice of parking facility and driver response to PGI messages would be fully justified. Research results could be incorporated in information-based traffic models without requiring extensive modifications. With relatively little lead time after the research results became available, the resulting model systems could be applied to the practical analysis of parking search traffic and its impacts, and ultimately to the design of PGI systems.

3.2.3 SPECIFIC SYSTEMS AND EXAMPLES

This section discusses a few specific examples of driver response to information. The examples were chosen either because of their intrinsic interest, or because a considerable amount of information is available about them, thus allowing a more detailed discussion than was usually possible in the preceding section.

3.2.3.1 Variable message signs

Variable message signs (VMS) have been widely installed for freeway traffic management in most metropolitan areas. VMS are electronic message boards located in the close proximity to roadways. They represent a cost-effective mechanism to display short real-time messages to drivers approaching them. Of course, their effectiveness in real-time traffic operations is highly dependent on user response to the displayed information. A compounding factor is that, unlike an in-vehicle navigation system that can provide personalized routing information, VMS are constrained to display generic information to all nearby drivers. It follows that seemingly minor details of the displayed message may have a considerable impact on system performance.

This provides motivation to study the relationship between VMS messages and user response. A few studies have investigated this relationship. (Peeta, Ramos et al. 2000) examined the effect of different message contents on driver response under VMS. The issue was addressed through an on-site stated preference (SP) user survey. Logit models were developed for drivers’ diversion decisions. The analysis suggested that content and level of detail of relevant information are factors that significantly affect drivers’ willingness to divert. Other significant factors included socioeconomic characteristics, network spatial knowledge, and confidence in the displayed information. Results also indicated differences in the response attitudes of semi-trailer truck drivers compared to other travelers. These results provide substantive insights for the design and operation of VMS-based information systems.

A somewhat similar study was performed by (Wardman, Bonsall et al. 1997), also using a stated preference approach to undertake a detailed assessment of the effect on drivers' route choice of information provided by a variable message sign (VMS). Although drivers' response to VMS information will vary according to the availability of alternative routes and the extent to which the routes are close substitutes, the research findings showed that route choice can be strongly influenced by the provision of information about traffic conditions ahead. This has important implications for the use of VMS systems as part of comprehensive traffic management and control systems. The principal findings were that the impact of VMS information depends on: the content of the message, such as the cause of delay and its extent; local circumstances, such as relative journey times in normal conditions; and drivers' characteristics, such as their age, sex and previous network knowledge. The impact of qualitative indicators, visible queues and delays were examined. It was found that not only is delay time more highly valued than normal travel time (which is to be expected) but also that drivers become more sensitive to delay time as delay times increased across the range presented.

Most disaggregate-level studies of drivers’ response to VMS use stated preference (SP) survey data rather than actual traffic data. It is generally not possible to infer from traffic measurements the effects of a VMS on individual driver behavior, since the drivers’ intentions prior to receiving the messages are not usually known. One study encountered during the literature survey used aggregate traffic data. (Yim and Ygnace 1996) used loop detector data from the *Système d'Information Routière Intelligible aux Usagers* (SIRIUS) information network in Paris to investigate the effects of VMS on link flows. Time-series traffic data were analyzed to measure changes in mean flow rates at a selected link. It was found that variable message signs influence drivers to choose less congested routes when the drivers are provided with real-time traffic information, and that a driver's decision to divert is closely associated with the information pertaining to the level of congestion. In the Paris region, drivers received prevailing queue length information from the VMS. According to the data analysis, a reported queue length of 3 km seems to be a threshold at which a significant number of drivers choose to divert to an alternative route.

3.2.3.2 Compliance with prescriptive guidance

The question of user compliance with ATIS messages arises when those messages consist of prescriptive recommendations about pre-trip departure time or route choices, or about en route path switching decisions. It is of considerable interest to understand the factors that influence whether or not a driver will follow the recommendation, both as a means towards better design of prescriptive ATIS messages (to ensure higher compliance), as well as to model more accurately the effects of such messages at the individual or the system level.

Given basic traffic data on travel times or other measures of network conditions, either descriptive or prescriptive messages could equally well be generated from them. However, it does not follow that drivers' responses to these two different types of messages would be identical. The format and content of the two types of messages would necessarily be different, and could well elicit different reactions from drivers.

Descriptive guidance is in some sense more "neutral", in that it simply conveys information about network conditions, which drivers will interpret as they wish and are able. In contrast to this, prescriptive guidance is a specific recommendation to do a particular thing; drivers may question whether the recommendation is based on sufficiently reliable data, on decision-making criteria consistent with their own, or indeed on a knowledge of the network equal to their own.

On the other hand, prescriptive guidance may potentially provide a traffic control center with a more direct influence over drivers' tripmaking decisions and so on network-level traffic conditions. A considerable amount of underlying traffic data may be efficiently synthesized in the form of a simple recommendation to drivers. Particularly under incident situations, a center may feel it appropriate to intervene aggressively in drivers' choice processes in order to minimize avoidable traffic impacts and to restore normal conditions as rapidly as possible.

It should be mentioned that the distinction between descriptive and prescriptive guidance messages is not an absolute one. Indeed, as will be seen below, there is considerable evidence that the most effective ATIS messages combine descriptive and prescriptive aspects: information that describes a traffic situation together with recommendations that suggest an appropriate reaction. The information explains or justifies the recommendation in some sense, and drivers are more likely to comply.

The most common source of prescriptive guidance currently in operation is variable message signs. These may be used to suggest routes to drivers based on broad destination locations ("take route XYZ for points north"). The limited space available for message display is a major constraint, and the messages must be carefully designed to be clear and understandable. (Bonsall and Palmer 1999) discuss various aspects of VMS message design, and (Summala and Hietamaki 1984) present an earlier study of factors influencing traffic sign effectiveness.

In-vehicle units have the possibility of making much more detailed and personalized recommendations, but are not yet in common use. An early prototype system of this type was Siemens' Ali-Scout system, which was used in West Berlin's LISB deployment (Bonsall and Joint 1991b) and also in Michigan's FAST-TRAK program. It is based around an in-vehicle device that provides a simple keypad for entering data, and outputs both visual (simple text and direction arrows) and audible (synthesized voice) messages to the user. System beacons are installed at key locations on the network; these both transmit data to the in-vehicle units, and receive from vehicles information on their recent travel times. At the beginning of a trip, when a user inputs his or her intended destination, Ali-Scout first indicates the general direction to follow based simply on compass direction. However, when the equipped vehicle passes a beacon, it receives real-time travel time information from which it can determine a minimum time path. The in-vehicle unit then provides detailed driving directions (direction to take at each intersection) until the vehicle arrives in the vicinity of the destination. At that point, the in-vehicle unit reverts to a compass-direction mode, since the density of beacons is not high enough for the system to be able to provide detailed local area directions.

It is difficult to obtain information on prescriptive guidance compliance rates from aggregate traffic measurements such as link volume counts. Determining whether a driver complied or not with a recommendation requires knowing what the driver's original intention was, and also depends on knowing whether a particular message is relevant to the driver's situation. Such information is not generally available at the aggregate level, although license plate survey methods and driver questionnaires have occasionally been successfully used for this purpose (Dudek, Weaver et al. 1978), (Richards, Stockton et al. 1978).

For this reason, most research on driver compliance behavior has been based on experiments with individual drivers using travel choice simulators. Travel choice simulators place experimental subjects in a decision-making situation and record their response. Travel choice simulators focus on decision-making related to travel behavior such as route and departure time choice. They are less elaborate than the (much more expensive) vehicle simulators that attempt to faithfully replicate all aspects of the driving experience. Rather, they provide only the key elements of a choice situation under study, with enough detail to establish the context and to motivate users to respond in a realistic fashion. A travel choice simulation experiment can be viewed as a kind of stated preference survey in which the hypothetical choice scenarios are presented in a rather realistic manner.

For their research in to VMS compliance, Bonsall and co-workers developed first the IGOR travel choice simulator (Bonsall and Parry 1990; Bonsall and Parry 1991) and then the more sophisticated VLADIMIR travel choice simulator (Bonsall, Firmin et al. 1997). Both of these were PC-based programs that allowed subjects to "drive" through a network from a given origin to a given destination, following a route of their choosing. During the "trip", the program displays information on local traffic conditions and, at decision points, may also provide ATIS messages. The user chooses how to proceed at each such decision point, and the program records each such decision along with data about the conditioning factors such as traffic conditions, messages displayed, and others. The experimenter can vary these factors from one run to another in order to investigate their effects on drivers' decisions. In VLADIMIR the display took the form of actual photographs of locations along the routes being driven, along with a simple sketch map of the nearby network, text describing traffic conditions and any ATIS messages, and basic information regarding the progress of the simulation (elapsed time, etc.)

After careful comparisons of driver choices in the simulator with actual decisions by the same drivers in comparable situations on the network, (Bonsall, Firmin et al. 1997) concluded that the simulator was able to replicate driver behavior with a high degree of fidelity.

Similarly, Mahmassani and co-workers (Chen and Mahmassani 1993; Srinivasan and Mahmassani 2000b) used a travel choice simulator interfaced to the Dynasmart mesoscopic traffic model. The model represents 20 minutes of peak period traffic in a freeway corridor carrying roughly 11,000 simulated vehicles on three parallel facilities with several opportunities to switch from one to another. Experimental subjects (possibly several at a time) make departure time and route choice and switching decisions. These decisions are taken into account by the traffic model, which computes the traffic conditions that result from them (as well as those of the many simulated vehicles). The ATIS messages provided to the subjects are derived from the computed decisions, and so are consistent with those decisions (rather than being exogenously specified.) Strictly speaking, the messages are descriptive rather than prescriptive: they indicate the travel time to the (unique) destination on each of the three main alternative routes. However, in the simple context studied, the minimum time route is clearly the recommended one; the other considerations mentioned above that might affect compliance behavior do not come into play.

Based primarily on the results of travel choice simulator experiments, a number of general conclusions about driver compliance with prescriptive guidance have been obtained. Examples of such general conclusions include:

- drivers will reject prescriptive messages that they do not find credible. Factors affecting message credibility include the extent to which it is corroborated by local evidence, visible to the driver, about the alternatives and their conditions; and the quality of advice previously (and particularly very recently) received from the system;

- compliance is strongly affected by the driver's familiarity with the network. For a given prescriptive message, the compliance by drivers familiar with the network is generally about 10% less than that by unfamiliar drivers;

- compliance is highest for messages that combine information and recommendations; next highest for those that provide information only; and lowest for those that make recommendations only;

- one minute of delay mentioned in a VMS message has the same effect, in terms of affecting path choice decisions, as 1.75 minutes of actual delay in driving time;

- compliance is higher for recommendations about an immediate action than for vaguer advice about actions in the future. A recommendation that refers to a nearby problem location is more likely to be followed than one that does not;

- drivers have a certain reluctance to switch to a new route from one that they are already following. The reluctance is greatest if the recommended route seems to follow an alignment significantly different from that of the current route;

- socio-economic characteristics of the driver are also important influences on compliance. Among these characteristics are gender, age, level of driving experience, and (as already mentioned) degree of familiarity with the network.

A number of attempts have been made to model compliance behavior. (Srinivasan and Mahmassani 2000b) consider route choice behavior as influenced by both compliance and inertia mechanisms. The inertia mechanism reflects a driver's reluctance to modify a decision already made, while the compliance mechanism reflects a driver's tendency to follow (or to reject) routing advice. They specify and estimate multinomial probit route choice models that include these two mechanisms as latent variables, and conclude that the effects are significant. Simpler route switching models often include a dummy variable that penalizes routes if they are different from the one currently followed.

(Bonsall and Palmer 1999) discuss more particularly the modeling of driver choice of exit link at an intersection when guidance is provided. They estimate a number of simple multinomial logit models that incorporate variables such as travel time, message specific indicators (e.g., mention of accident or of road works), alignment of the exit link relative to current path, and so on. These models are intended for use in traffic simulation systems to predict the probability that individual drivers will proceed via the different possible exit links.

3.2.3.3 Shopping trips

Most studies on ATIS have focused primarily on commuting trips, which go to a fixed destination, tend to be repetitive in nature and involve tripmakers who are familiar with the transportation network. But it also of considerable interest to examine traveler response to ATIS during non-commute trips, where travelers have some flexibility in terms of destination choice and may not be as familiar with the transportation system.

(Mahmassani, Huynh et al. 2001) and (Kraan, Mahmassani et al. 2000) examined behavioral responses of non-commuters under real-time information during shopping trips. Utilizing results from an interactive stated-preference internet-based survey, the authors developed discrete choice models to investigate factors that influence en-route switching to alternate destinations and alternate routes during such trips. The fundamental difficulty in modeling this phenomenon derives from the manner in which information is provided to assist trip-making. The information provided and resulting user choices are interdependent. That is, the choice set presented to a tripmaker at a particular decision point is predicated on his/her previous decisions. Conversely, a tripmaker's decision in turn alters his/her subsequent information and choice sets.

The authors specified a model structure that overcomes this difficulty. It explicitly captures the conditional nature of the decision process. The model that they developed provides insight on en-route diversions during the shopping trip together with the factors affecting these decisions, especially with regard to the role of real-time information.

3.2.3.4 Transit information systems

Transit information systems provide transit users with static information on service such as routes, schedules, transfers and fares. They may also offer real-time information such as the anticipated arrival time of the next bus or train, and individualized information such as the route to follow or the expected travel time of a particular trip the user intends to make. Ultimately, transit information systems may offer their users a full range of trip planning, ticketing and real-time information services, integrated across the range of public transport modes; the Transport Direct system, currently under development in the U.K., ((Lyons, Harman et al. 2001)) is an ambitious step in this direction. (Casey, Labell et al. 2000 Section 3) provide a useful summary of the North American state of the art in transit information systems as of the year 2000. It is fair to say that currently deployed systems still have very rudimentary capabilities compared to their ultimate potential.

Real-time transit information can reduce the anxiety that users feel due to uncertainty regarding the duration of their wait. More generally, it may improve the quality of service perceived by transit users and likely increase transit's retention of its current patrons. Furthermore, providing information may possibly change non-users' attitudes toward public transit, and entice more travelers to use public transit.

A relatively limited number of studies have been undertaken to investigate the usefulness of these systems in attracting new transit passengers and improving the level of service of existing passengers. (Abdel-Aty 2001) used ordered probit models to study the effect of Advanced Traveler Information Systems (ATIS) on transit ridership. A computer-aided telephone interview was conducted in two metropolitan areas in northern California. The survey included an innovative stated preference design to collect data that address the potential of advanced transit information systems. The study's main objectives are to investigate whether advanced transit information would increase the acceptance of transit, and to determine the types and levels of information that are desired by commuters. The survey included a customized procedure that presents realistic choice sets, including the respondent's preferred information items and realistic travel times. The results indicated a promising potential of advanced transit information in increasing the acceptance of transit as a commute mode. It also showed that the frequency of service, number of transfers, seat availability, walking time to the transit stop and fare information are among the significant information types that commuters desire. Commute time by transit, income, education, and whether the commuter is currently carpooling, were factors that contributed to the likelihood of using transit following information provision.

Although such transit information systems are assumed to be of benefit, methods for evaluating these benefits under various conditions are limited. (Mishalani, McCord et al. 2000) developed a methodology that focuses on the potential benefits of bus arrival information systems to passengers waiting at bus stops under various supply and demand characteristics. Transit bus operations and passenger arrivals are modeled as a stochastic system where the operator uses real-time bus location data to provide to waiting passengers bus arrival time information that maximizes passengers' utilities. Simulation results reveal how the value of such information systems depends on the type of real-time data available to the operator, on bus operations characteristics, and on demand patterns. Results indicated that while the first two influence the value of information to passengers, demand patterns do not have a significant impact.

3.2.3.5 ATIS for maintenance and protection of traffic around construction zones

It is natural to think of applying ATIS to help manage traffic in and around construction zones. Such zones can create significant traffic disruptions. Because of their temporary and changing nature, most travelers will not be able to learn by experience what "typical" conditions are or how to avoid the most impacted areas. It is logical to suppose that providing real-time information to drivers in such circumstances would produce real benefits both to individual drivers and to network traffic conditions overall.

Surprisingly, there are very few examples of the use of real-time traffic information systems for construction zone traffic management in the U.S., and very little literature on the subject.

(Kratofil 2001) provides a brief but useful review of relevant literature. Based on his literature review, he then proposes a framework for quantifying the benefits of ATIS in construction zone traffic management, applying for this purpose a standard breakdown of ITS impacts into a number of such as mobility, safety, etc., and distinguishing between impacts to drivers, to the implementing agency, and to the community at large. He compares a "with" and "without" ATIS situation for a specific interstate highway reconstruction project using this framework. In most cases, quantification of the impacts of ATIS relies on values (for example, accident rate reduction impacts) that were derived for situations other than construction zone traffic management. He concludes his paper with a recommendation for collection of traffic data before and during the operation of the ATIS for construction zone traffic management, in order to begin accumulating quantitative results that could be useful for future design and evaluation efforts involving such systems. He also recommends the execution of surveys to better understand people's usage and valuation of information from ATIS.

There is clearly considerable scope for ATIS MPT applications. Very little definite knowledge is available regarding either the design and operation of such systems, or traveler response to them.

3.3 What kinds of information do users want? How much will they pay for it?

In 1991, (Green, Sarafin et al. 1991) discussed the results of a study by a panel of experts of features that should be in driver information systems by the year 2000. To determine this, features were evaluated on the basis of three objectives that had been set by USDOT: (1) their effect on accidents; (2) their impact on traffic conditions; and (3) their fulfillment of driver needs. The analysis considered a very broad range of possible functions including communications, entertainment, office capabilities, way-finding, vehicle status monitoring, display of traffic signs and signals inside the vehicle, road hazard alerts, and traffic information. For each such function, the experts considered a variety of possible features that might implement the function. (In the entertainment function, for example, the possible features considered were cassette/CD player, radio and television.) Each feature was then ranked according to its contribution towards the stated objectives.

The five highest-ranked features were crash site hazard notification, in-car display of external traffic control signals, information on traffic congestion, indication of the presence of multiple compounding hazards in a driving situation, and information about road construction activities. All of these features are components of what we would now call an Advanced Traveler Information System, although some are still more advanced than is anything that has been prototyped to date. Features considered in the study which were given some of the lowest priorities, such as cellular telephone communications capabilities and radar detectors, are by now commonplace.

Considerable work since that time has attempted to identify user preferences for travel information system features. In this context, the term "features" refers to the different *kinds* and *qualities* of messages that might be provided by a traveler information system. By kinds of messages is meant the nature of the data provided in the messages – information on travel times or delays, location of incidents, specific route recommendations, etc. By quality of messages is meant their usefulness as it might be judged by a user – how up to date they are (their currency), their accuracy, precision, network coverage, the degree to which the message relates to the traveler's individual situation, and so on.

User preferences are obtained from various kinds of traveler surveys. In some cases, survey respondents are simply asked to express an opinion about various possible features: to state whether a feature is desirable or not, or to indicate the strength of their desire for the feature on an ordinal scale. Other survey methods involve placing the respondent in (hypothetical) situations where they must state their preference between alternative features, and so illuminate his or her tradeoffs between the features. Survey results may be analyzed by computing simple descriptive statistics or by estimating some form of econometric model. A number of these were discussed in the preceding sections.

(Llaneras and Lerner 2000), in a recent study of this type, compared user response to and preference for “basic” and “enhanced” ATIS services in the context of en route decision making; he used travel choice simulation experiments for this purpose. In these experiments, basic ATIS services consisted of descriptive information on incidents and congestion levels, and qualitative estimates of travel delays; enhanced services included all the basic services, but added information on alternative routes, various details about incidents, and a map display showing real-time traffic conditions. By analyzing the effectiveness with which users were able to translate the information received into travel improvements, the authors concluded that the following types of information were most valuable: data on incident location, type and delay; data on queue lengths; and recommendations about alternative routes, with directions to them. The real-time map display of traffic conditions was the information most frequently referred to by drivers in the experiments; however, human factors questions remain unsolved regarding the best way to present such information with minimal interference to driving.

When the survey choice situation involves both information features and money, it becomes possible to estimate an implicit willingness to pay for the feature, defined (in a utility based model) as the negative ratio of the marginal utilities of the feature and of money.[1] It must be emphasized that, to date, very few travelers have ever paid any money to receive travel information.[2] Answers about money in stated preference surveys are frequently biased because respondents know that they will not actually have to pay anything, regardless of what they say. Therefore, conclusions about willingness to pay for travel information are fraught with uncertainty, and the numbers obtained from such surveys should be interpreted in relative rather than absolute terms.

(Wolinetz, Khattak et al. 2001) list six broad factors that they hypothesize may affect travelers' willingness to pay for information:

- uncertainty: if there is little variability in traffic conditions from trip to trip, these is little need for real time traffic information. Non-recurrent congestion increases travel time uncertainty. Recurrent congestion, even through it is relatively more predictable, also adds uncertainty. Both of these effects may increase with trip length;

- information awareness: travelers who are aware of available ATIS services are more likely to express a willingness to pay for future services;

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[1] When features are defined in discrete terms (e.g., information coverage of freeways only, of freeways and arterials, or of all roads), the "marginal" utility of a feature is the difference in systematic utility between two successive levels of that feature.
[2] This is beginning to change with the increasing number of new vehicles that offer in-vehicle navigation devices as a purchase option. However, the types of information currently provided by these devices is not yet as high quality as that assumed in most ATIS stated preference surveys.

- access to information: individuals who are willing and able to access real-time information through communication or computing devices may be more likely to pay for ATIS services;

- information use: individuals who already receive travel information via phone, radio or other conventional sources may be more willing to pay for ATIS services;

- situational and contextual factors: such as trip purpose, departure or arrival time flexibility, trip chaining requirements, and many others;

- socio-economic factors: background variables such as age, gender, income and education may be important influences on the willingness to pay for ATIS.

Research at the University of Michigan Transportation Research Institute (UMTRI) (Wallace and Streff 1993) studied the stated rankings of different types of travel information by drivers on different kinds of trips (commute trips, trips in a familiar area and trips in an unfamiliar area). This research compiled descriptive statistics on respondents' rankings of the relevance of different types of information on the route choice decision. The researchers were particularly interested in the influence of the different information types in the en route decision to switch from one route to a different one. For commute trips and those in familiar areas, information on travel delays and travel time reliability on the original and alternate routes were ranked the most highly. For trips in unfamiliar areas, the availability of travel directions for the alternate route was a highly ranked consideration.

(Mehndiratta, Kemp et al. 1999a) (see also (Kemp and Lappin 1999)) surveyed drivers who had had significant experience with prototype in-vehicle navigation devices in three recent field operational tests. Drivers' preferences with regard to information update frequencies, network coverage and information personalization were investigated in a series of attitudinal and tradeoff questions. The survey results were analyzed in a number of ways, including by estimating logit-form models of preference probabilities as a function of information quality and price. In general, the authors found that the most basic improvements in information quality over currently-available sources (general radio traffic reports, for example) were highly valued, but that further information quality improvements exhibited a pattern of decreasing incremental utility.

Geographic coverage and update frequency were both important attributes; logit model coefficients for the minimal level of provision of both of these had approximately similar coefficients. With respect to geographic coverage, door-to-door coverage was perceived as having little or no incremental benefit compared to coverage of freeways and arterials. Similarly, information updates several times an hour were clearly preferred to static information, but the added value of nearly continuous updates was small to negligible. Personalized information provision was not highly valued.

Few respondents were indifferent to the type of guidance – prescriptive or descriptive – provided by the system; they strongly preferred either one or the other. A majority of all respondents preferred to receive descriptive information (delays), although about 20% preferred prescriptive route guidance. Where sample sizes were large enough to allow such investigation of gender-related effects, it was found that women were more likely than men to prefer prescriptive guidance.

Most respondents indicated some willingness to pay for real-time traffic information; few indicated that they would not pay anything. The estimated willingness to pay ranged from $8-$10/month in Seattle, from $28-$36/month in Chicago and from $8-$20/month in Boston, depending somewhat on the particular information types and qualities considered. These values are higher than what is generally expected from other, perhaps more informal, analyses of user willingness to pay.

(Wolinetz, Khattak et al. 2001) is another recent investigation into user preferences and willingness to pay for different types of travel information. The survey covered both automobile and transit users in the San Francisco Bay Area, and asked respondents to rank possible information features of a hypothetical traveler information system; it also included pricing questions. Survey analysis was based on the computation of descriptive statistics. The most desirable information content options were constant updates, alternate route information, in-car computer information, expected delay data and route time comparisons. Many respondents indicated a willingness to pay at least some positive amount for high-quality real-time traffic information. The majority of these people prefer to pay on a per-request basis (as opposed to a flat monthly subscription fee.) Most expressed a willingness to pay up to $1 per request.

(Tsai 1991) reports on the results of focus groups held with commercial vehicle operators (truckers and bus drivers) regarding their preferences for information about the highway environment: traffic and weather. Desirable features included in the traffic data were: information on traffic congestion, accidents, lane closures, bridge closures, construction updates, alternate routes, low bridges, road weight restrictions and legal truck routes. Truckers identified specific areas (generally around the largest metropolitan areas) where such information would be particularly useful. Weather information needs included: notice of adverse or severe weather conditions, fog conditions, and identification of areas experiencing black ice. However, the expressed willingness to pay for such information was quite low.

(Ng and Barfield 1997) report on surveys of ATIS feature requirements of both private and commercial vehicle operators. Alternate route information was highly valued by all these users. Respondents indicated that the main reasons for choosing an alternate route were accidents, traffic volume levels and road construction activities. Around half the private and commercial drivers cited the gain in time by rerouting as the reason for switching routes. Accuracy and currency were found to be the most important attributes of the information provided by an ATIS or CVO application. Because drivers' observations of traffic conditions play an important role in motivating a route switch, the authors suggest providing live displays of real-time traffic conditions as a component of a traffic information system. They also suggest providing information (either en route or post trip) that confirms and validates the decisions actually made by a driver, in order to build confidence in the use of ATIS.

Survey and analysis issues that arise in investigations of user preferences for possible travel information system features are addressed directly or indirectly in a number of references in the literature. (Ng, Barfield et al. 1997) provide a high-level overview of survey design and analysis methods that might be applicable to such investigations, and furnishes extensive details about survey design issues and their resolution in several case studies. (Mehndiratta, Kemp et al. 1999a) discuss a number of stated preference survey design and analysis issues, including the possible presence of response bias (respondents give positive answers thinking it will please the surveyor) and non-commitment bias (respondents overstate their willingness to pay because no money is actually committed by answering). The authors also investigated the econometric problem of correlated error terms in the response by a single person to multiple related questions. They addressed the problem by specifying and estimating random parameter logit models, but found that this computationally-intensive technique did not result in estimates significantly different from those obtained using simple logit models.

3.3.1 ATIS MESSAGE RELIABILITY

Reliability is a feature of particular prominence in analyses of ATIS message attributes. Generation of high accuracy ATIS messages is a challenging technical task, for a number of reasons. Measurements of traffic conditions on a network will generally be made using a limited number of data collection devices (traffic detectors, probe vehicles, cameras, etc.) The measurements will inevitably be imperfect (imprecise and inaccurate) for a variety of technical reasons. Information of particular interest, such as assessments of the severity and clearance time of incidents, may not even be available until after special personnel (police, traffic crews) physically reach the incident site. Data communications and processing limitations mean that traffic measurements cannot be instantaneously converted into meaningful traffic messages. From imperfect measurements of a limited number of variables processed at time intervals that are large compared to characteristic times of traffic dynamics, it will be difficult, to say the least, to obtain and maintain a detailed and up-to-date picture of prevailing traffic conditions.

Furthermore, data on prevailing conditions may not be an accurate basis for determining the conditions that a vehicle will actually encounter on a path. (Ben-Akiva, de Palma et al. 1996) show analytically that use of prevailing conditions for ATIS messages can lead to a worsening rather than an improvement in traffic conditions, and explore the sensitivity of ATIS messages to inaccuracies and imperfections in traffic conditions. (Chen and Mahmassani 1991) investigated, using a mesoscopic traffic simulator, the reliability of route guidance recommendations based on prevailing times. They compared minimum paths and path times based on prevailing times with the actual minimum paths and path times using true (i.e. time-varying) link times and concluded that real-time ATIS messages based on "information on currently prevailing link trip times, with no attempt to predict future travel time or traffic conditions, may not be very reliable, especially at high levels of market penetration." However, guidance based on predicted traffic conditions requires forecasts and models, which may not be particularly accurate, and involves large amounts of computation, which will add to the time delays of the provided information. Thus, predictive guidance, even if it has the theoretical possibility of better matching a driver's actual travel experience, may be constrained in its accuracy by practical and computational factors.

A number of studies of user preferences for ATIS features have included consideration of message accuracy, as has been seen. (Madanat, Yang et al. 1995) included drivers' perceptions of information reliability as a latent (unobservable) variable in a route switch model and found it to have both direct and indirect effects on the probability of switching in response to information; the indirect effect came through its influence on drivers' general attitudes towards route diversion (another latent variable in the model). (Hato, Taniguchi et al. 1995) developed stated choice models of route switching behavior in which the accuracy of reported travel times was explicitly varied in different choice situations, and found that the information accuracy level was a significant variable in determining switching probability.

(Kantowitz, Hanowski et al. 1997a; Kantowitz, Hanowski et al. 1997b) explicitly consider the question of how much inaccuracy ATIS users will tolerate. They pose the issue in terms of the relative strengths of drivers' self-confidence in their knowledge of traffic conditions, and their trust in the ATIS messages. The authors conducted experiments using a travel choice simulator in which information on link conditions (light or heavy traffic) was intentionally degraded. They considered situations in which either 73% or 41% of the links had correct information. (These numbers come from prior work by the authors on reliability issues in human factors. Of course, in some cases, the incorrect information is harmful –when driver chooses a heavily congested link because it is reported to have light traffic, for example –while in others the error may be relatively benign.) They found that when 73% of the link reports were accurate, drivers still took account of the messages; while when only 41% were accurate, drivers ignored them. Drivers did not use accurate information as effectively in the familiar setting as in the unfamiliar setting. Also, inaccurate traffic information was more harmful in a familiar setting. Thus, it would appear that drivers are tolerant of a certain amount of error in ATIS messages, although drivers familiar with an area will expect a higher degree of accuracy from the information system.

3.4 User benefits from ATIS

The economic benefits that an ATIS user derives from ATIS services are very closely tied to the user’s response to ATIS and to his or her willingness to pay for ATIS information: they are all aspects of the same internal evaluation and decision-making process. The discussions in Sections 3.2 and 3.3 have covered many aspects of ATIS user benefit evaluation.

It has been seen that the spectrum of possible user responses to ATIS information is vast, ranging from relatively simple behavioral responses like route switching to complex responses such as re-arranging ones schedule of daily activities. This range exceeds the gamut of responses conventionally considered in transportation benefit evaluation exercises, and indicates that considerable care must be taken in thinking about and quantifying their benefits.

In conventional evaluation approaches, user benefits are usually computed as a change in consumer's surplus, defined as the total difference between what each user is willing to pay (in money or in time) for something and the amount actually paid. Willingness to pay is deduced from the travel demand curve, expressing the amount of travel that would be made at different cost or time levels. The evaluation thus assumes that user benefits are tied to travel cost or time reductions.

This assumption is unlikely to lead to a complete and comprehensive approach to evaluating ATIS-produced user benefits. For example, peoples' re-arrangement of their daily activity schedules may lead to more rather than less time being spent in travel, as they are able to carry out more activities because of more precise planning. If one were to ask such people if they were better off because of ATIS, they would reply affirmatively, even though they spend more time traveling: the benefits they derive from the additional things they do more than offsets the opportunity cost and disutility of the time spent traveling. If this were not true, they would not have re-arranged their schedule.

Special cases of ATIS-produced benefits can be distinguished, and may lead to simplified evaluation procedures when it is known what are the preponderant impacts of ATIS in a particular situation. In general, of course, it will not be possible to know *a priori* what the main impacts of an ATIS on user behavior are likely to be.

For example, if the only effect of an ATIS is to cause someone to switch routes, it might be reasonable to evaluate the ATIS user benefits via the resulting savings in travel time or cost. (If the user has confidence in the ATIS, an additional benefit may derive from the reassurance of having made an *informed* route switch, as opposed to the stress that could accompany an uninformed decision.) However, as noted above, there are indications that ATIS-produced reductions in travel times are likely to be small, and that the most common effects of pre-trip ATIS will be in terms of departure time rather than path choice changes.

If the only effect of the ATIS is to provide more precise estimates of the travel time between activities at two locations, and so allow the user to spend more time at either trip endpoint, then it might be reasonable to evaluate the ATIS user benefits via the benefits of pursuing those endpoint activities. In this way, an estimate of the benefits of improved travel time reliability could be obtained.

(Small, Noland et al. 1999) carried out and analyzed stated preference surveys investigating the value of travel time savings in congested conditions, and the value of travel time reliability, to travelers and freight carriers. They found that travelers definitely impute a monetary value to travel time reliability; however, this value can be entirely explained in terms of the early or late schedule delay costs at the destination (i.e., the cost to a traveler of arriving earlier or later than her intended arrival time). After the schedule delay costs were accounted for, no residual valuation of travel time reliability could be detected from the survey results. Similar results were found for freight carriers, although the conclusions were less statistically robust: travel time reliability had a value to freight carriers, but this value was entirely attributable to the costs of late arrival compared to a scheduled time.

Brand (1998) has proposed a more general user benefit evaluation method that returns to the original economics approach based on willingness to pay. However, instead of attempting to estimate willingness to pay from a conventional time- or cost-based demand curve, he suggests estimating it directly, using stated preference surveys of current or potential users of ATIS services. Such surveys can pose questions in which respondents trade off service attributes against cost and, properly conducted and analyzed, can provide reliable information on users' willingness to pay for different service attributes or for entire systems. A number of willingness to pay results from stated preference surveys were discussed in the preceding section.

By obtaining willingness to pay in this direct fashion, many of the complications of a model-based approach are avoided. There is no need, for example, to estimate how ATIS users might re-arrange their daily activity schedules and tripmaking behavior, and then to evaluate the travel and non-travel benefits and costs of the re-arrangement: the effects of such possible changes are already incorporated in the users' responses to the stated preference surveys. This user benefits estimation method has the potential of being both simpler and more accurate than adaptations of conventional transportation evaluation methods to the very different properties of ATIS, although the usual caveats regarding stated preference surveys continue to apply.

3.5 Day-to-day effects and learning

ATIS is a new and evolving set of technologies, and new ATIS users will need to learn about its features, capabilities and performance. While learning about and using ATIS, individuals will inevitably have a variety of experiences with it, both positive and negative. Over time, these experiences will in some way shape peoples' attitudes towards and use of ATIS. At a larger scale, the mechanisms by which people learn about ATIS and filter their experiences with it will strongly affect the public's overall acceptance or rejection of ATIS technologies.

Perhaps for these reasons, a number of researchers have investigated the day-to-day learning processes associated with ATIS. Indeed, it appears that this subject has already been more intensively investigated than learning processes associated with conventional traffic equilibrium.

(Iida, Akiyama et al. 1992) provide an example of a study of learning processes in a conventional equilibrium context. They analyzed the dynamics of route choice behavior in simulator-based experiments that asked the participants to respond to repeated hypothetical route choices. In the analysis, travelers depart from a single origin to a single destination connected by two parallel alternative routes. Day-to-day variations in traffic conditions are represented by route travel time changes. Travel time prediction errors (the difference between predicted and actual travel time) as well as actual travel times are treated as "experiences" accumulating through the experiments. It was found that assumptions about learning behavior strongly affected the day-to-day variability of traffic flow; however, none of the assumptions considered led to flow equilibrium. The authors conclude from this that existing traffic assignment models may not be adequate representations of actual traffic phenomena.

In the context of ATIS, (Iida, Uno et al. 1999) performed a study to identify changes in drivers' route choice mechanisms following the introduction of ATIS. They also investigated the influence of the accuracy guidance information on the route choice mechanism. The study used a travel choice simulator with which subjects repeatedly traveled between the same origin and the destination in the morning. During the experiment, the subjects learned about, and accumulated knowledge of, the network and information system. It was found that introduction of ATIS did change the decision mechanism that drivers applied, and that the quality of the provided information affected the nature and permanence of the change.

A similar study performed by (Vaughn, Abdel-Aty et al. 1993b) analyzed the accuracy of information provided in modeling drivers' sequential route choices. This study also used discrete choice modeling framework to model sequential route choices. Experimental sequential route choice data under the influence of ATIS was collected using a PC-based travel choice simulator. The experiment collected information on drivers' pre-trip route choice behavior at three levels of information accuracy: 60 percent, 75 percent and 90 percent. An analysis of variance was performed on the data to investigate the interrelationships among the different variables in an attempt to identify factors that significantly influence route choice behavior and learning. An attempt was made to model sequential route choice behavior using a binary logit model formulation; the results were mixed. It was assumed that drivers update their knowledge of the system based on their previous experiences; therefore an information updating function was specified and incorporated into the model. The results indicate that drivers can rapidly identify the accuracy level of information being provided and that they adjust their behavior accordingly. There is also evidence that indicates that an accuracy threshold level exists, below which drivers will not follow advice and above which drivers readily follow advice.

(van Berkum and van der Mede 1999) proposed a very general dynamic model of ATIS-guided route choice that includes behaviors based on perceived utility maximization, habitual choice and compliance with prescriptive guidance. Irrespective of the choice rule operating, individuals learn from their experiences. After each trip, the experienced travel time is used to update the mean expected travel time and the travel time variance for the chosen route. Descriptive and prescriptive guidance information influence route choices in different ways. Descriptive information may be incorporated into the perceived utility of alternatives for the subsequent choice. Prescriptive guidance can overrule the perceived utility maximization and habitual choice behaviors. The degree to which guidance affects the decision depends on the credibility of the information, and the credibility is influenced in turn by previous experiences with the information system.

In modeling dynamics, it is necessary to observe the behavior of a decision-maker over time. Investigating route switching in a dynamic context enables the calibration and testing of richer model specifications by incorporating repeated measurements, heterogeneity, within-day and day-to-day influences of variables, and state dependence effects. The multinomial probit framework (MNP), though well suited to tackle these challenges in dynamic models with a few periods, is prohibitively expensive for panels of longer duration.

To address the needs of modeling dynamic route switching over a large number of decision periods, (Srinivasan and Mahmassani 2000a) proposed a dynamic kernel logit model that retains the flexibility of multinomial probit while exploiting to some extent the computational tractability of the logit model. They applied the model to analyze the influence of systematic effects on route-switching behavior under ATIS. The effect of trip maker characteristics, trip characteristics and traffic conditions, experiences in traffic, and attributes of ATIS information are examined in this context. They also investigated heterogeneity effects in route switching behavior. Finally, time-dependent effects in route switching behavior are examined in two ways. First, at the systematic level, the influence of past experiences on current behavior is assessed. Second, dynamic effects were investigated via the structure of the utility disturbance terms. At the unobserved level, time dependence effects are examined by specifying suitable variance components. The variance-covariance structures are tested for the presence of temporal correlation (both within day and day-to-day), in addition to serial correlation (due to repeated measurements).

Many analyses of driver-network transportation systems assume that the systems are in equilibrium. Equilibrium analyses presuppose that the driver is rational and homogeneous, and has perfect information. (Nakayama, Kitamura et al. 2001) suppose, on the contrary, that people have cognitive limitations. A driver is assumed in this study to adopt simple rules when choosing a route. The authors develop a simulation system in which drivers' learning is simulated through a genetic algorithm that, over time, that generates and modifies a set of route choice decision rules. The results of simulation analyses can be summarized as follows: Drivers do not become homogeneous and rational as equilibrium analyses presuppose; rather, there are less rational drivers even after a long process of learning, and heterogeneous drivers make up the system. Drivers' attitude toward and perceptions of each route do not become homogeneous either, but become bipolar. The results point to the need for a critical appraisal of the foundation of the equilibrium analysis of network flow.

(Ozbay, Datta et al. 2001) proposed the use stochastic learning automata (SLA) to analyze drivers' day-to-day route choice behavior. This model addresses the learning behavior of travelers based on experienced travel time and day-to-day learning. In order to calibrate the penalties of the model, an Internet based Route Choice Simulator (IRCS) was developed. The IRCS is a traffic simulation model that represents within day and day-to-day fluctuations in traffic and was developed using Java programming. The calibrated SLA model was then applied to a simple transportation network to test if global user equilibrium, instantaneous equilibrium, and driver learning have occurred over a period of time. It was observed that the developed stochastic learning model accurately depicts the day-to-day learning behavior of travelers. Finally, it is shown that the sample network converges to equilibrium, both in terms of global user and instantaneous equilibrium.

While many travel behavior studies that deal with day-to-day learning have focused on modeling route choice behavior under information, fewer have examined day-to-day processes in departure time choice behavior with ATIS. The motivation in modeling departure time choice dynamics stems from the following considerations. The departure time decisions of commuters on a given day significantly influence the within-day distribution of traffic, congestion and queuing patterns on the network in the peak period. Accurate models of departure time adjustments can translate into a robust time-dependent OD prediction capability that is an essential component for dynamic traffic modeling and assignment techniques. In addition, since departure time variations influence the network flow evolution from day-to-day, models of departure time choice dynamics are important for characterizing and analyzing dynamic network states and the associated costs. Dynamic models of departure time choice play an important role in demand forecasting, as an integral component of activity-based demand modeling framework.

(Mahmassani and Chang 1986) performed an exploratory analysis that included 1) the explicit treatment of the day-to-day dynamics of departure time decisions, 2) the specifications of mechanisms by which individual users adjust their decisions on a daily basis, given prior experience, 3) the boundedly-rational heuristics that are assumed to govern individual tripmakers' behavior, and their use in a modeling framework that recognizes the interaction between user behavior and system performance, and 4) the use of a special-purpose traffic simulation model to study the dynamics of user behavior. An extension of this work was conducted by (Mahmassani and Stephan 1988) in two directions: 1) the inclusion of the route choice dimension in addition to that of departure time and 2) the consideration of two user groups with different information availability levels interacting in the same simulated commuting system. The effect of information availability on the behavior and performance of given user group was of particular interest. In this regard, the results of this experiment are broadly consistent with a priori expectations; that is, users with more information clearly outperform those with limited information when both are competing in the same system. The interdependence between route choice and departure time decisions is another important aspect of user behavior addressed in this paper. The exploratory aggregate analysis considered here points to the precedence of departure time shifts over route shifting in dealing with experienced unpredicted congestion in the system.

The above mentioned works in day-to-day departure time choice modeling do not propose specific models of the departure time adjustment process. (Srinivasan and Mahmassani 2001) addressed this by investigating alternative mechanisms commuters' day-to-day departure time adjustment behavior. The mechanisms they considered include: utility maximization from unordered alternatives; ordinal response mechanism (where thresholds are corresponding to choice alternatives are ordered); sequential greedy search process; and a two-stage nested adjustment process. Econometric models are proposed corresponding to these mechanisms and implemented using departure time adjustment data obtained from interactive simulator-based experiments. The results indicate that the observed departure time choice dynamics is consistent with a sequential greedy search process. Under this mechanism, users continue to search for acceptable adjustment alternatives in a sequential and ordered fashion, until a satisfactory departure time choice is obtained. The results also indicate that network conditions, users' past experiences in the short and longer-term, and the nature and type of real-time information supplied by ATIS significantly influence the adjustment behavior of commuters. The models and results have significant applications in demand forecasting, network state prediction, and the evaluation of transportation control measures.

All of the above studies considered single-purpose trips from origin to destination. In fact, many trips involve multiple purposes and intermediate stops; this is called trip chaining. Trip chaining can significantly impact travelers' route and departure time switching behavior. Trips with intermediate stops are more likely to involve switching than trips without stops. (Mahmassani, Hatcher et al. 1991) addressed the daily variation of trip-chaining behavior of commuters, and related it to various attributes of the commuter, the workplace, and the commute. The paper addresses the day-to-day variation of three key aspects of the home-to-work commute: 1) the time of departure from home; 2) the frequency, purpose, and duration of intervening stops between home and work; and 3) the path actually followed through the network. It is based on two-week detailed diaries of actual commuting trips completed by a sample of auto commuters in Austin, Texas. About 25 percent of all reported commutes contained at least one non-work intermediate stop, underscoring the importance of trip chaining in commuting behavior. These multipurpose trips are shown to influence significantly the departure time and route-switching behavior of commuters.

Although considerable attention has been given to incorporate day-to-day learning in route and departure time choice modeling, the same cannot be said about modeling mode choice. The only work that was found during the course of the literature review is by (Aarts, Verplanken et al. 1997). This study focuses on travel mode choice behavior in order to test theoretical propositions as to habitual decision making. It investigates the effects of habit on information processing during judgments of travel mode use. The study used multiple regression analysis to test the hypothesis that habit is negatively related to the elaborateness of information processing preceding judgments of travel mode use. The study focused on the judgment of bicycle use for short distance trips. It is expected that individuals who have developed a strong bicycle choice habit apply less elaborate information processing strategies compared to those who have not developed such a habit.

3.6 Human factors issues

A driver's ability to navigate through a complex environment is largely dependent on the type and extent of cognitive structures representing that environment, the goals of the driver, and the ability of the driver to stay oriented. These three areas, founded in psychology and environmental cognition, are functionally related. First, a destination and travel plan must be formed. Second, knowledge of the local or global network must be known or acquired. Finally, a reference system must exist to relate the driver to the environment. The cognitive map has been hypothesized as the basis for mentally storing or representing information about the physical world. The internal format of remembering this information could have profound effects on the ease with which one can assimilate information presented by an Advanced Traveler Information System (ATIS). If the information is mentally stored in a prepositional format, then specific verbal directions may be desirable. However, if the information if the information is in a format analogous to the real world, a different representation, the map for example, may be desired. In addition, the spatial and verbal skills of drivers may vary significantly among individuals; thereby influencing their ability to use different navigational display formats. Human factor issues of concern include the format and coding of navigation system information, the attentional demand and safety issues of displays and controls, and agreement on general guidelines for the development and manufacture of ATIS.

A number of research studies have been reviewed that deal with human factors involvement in the design and use of ATIS. Some of them deal with the application of human factors guidelines and design decision aids for ATIS and ATIS displays. The questions that the designers must answer when developing displays for ATIS, which will affect or have an impact on both the safety and usability of the system are: (i) What information should be included in the ATIS that is being developed? (ii) What functions of the ATIS should the driver be allowed to use? (iii) To which sensory modality (e.g., auditory, visual, tactile) should information items be allocated? (iv) What format (e.g., text, map, tone, voice) should be used to present the information?

(Mollenhauer, Hulse et al. 1997) explored the decisions that designers must make when developing ATIS displays. They described a design support process that has been developed to help formulate answers that reflect current human factors research and accepted design principles. Examples of decision tools that make up this process are provided along with a description of how these tools can be used together to aid in the design process. To analyze the information format options, "trade study" analysis is used to aid in design decisions. These analyses serve as systematic aids for complex decision making. In addition, specific results are also presented and discussed.

(Landau, Hanley et al. 1997) reviewed the following topics for guideline availability and applicability to an ATIS:

- input methodology: The design of the input mechanisms for an in-vehicle system must consider the accuracy and speed required for transactions;

- display and information characteristics: The research covers guidelines related to both legibility and readability of a display;

- auditory display characteristics: Auditory displays include both nonverbal and verbal aural displays. Nonverbal displays use auditory alerting signals to signify events. Verbal displays use voice signals or messages to signify events and to provide more complex information. Auditory displays can supplement visual systems;

- human-computer interaction: The interaction between a driver and an ATIS system will be modeled to a great degree on human-computer systems because the nature and complexity of the transactions are so similar to current computer interfaces. Therefore, the applicability of human-computer interface guidelines is reviewed; and

- navigation information format: Navigation information is typically portrayed by maps that provide direction and distance relationships in a plan view presentation. Another type of navigational format is turn-by-turn sequential list.

The successful implementation of ATIS depends on user acceptance of its products and services. Information on user acceptance could be applied to the design of ITS products and services, as well as to the development of ATIS implementation strategy. User acceptance is particularly important to the successful implementation of ATIS because the accuracy of traffic information it conveys is dependent on the number of ATIS equipped vehicles. Receiving inaccurate information from an ATIS device may break the trust the driver has in the system and lead to user rejection. Consumer rejection of ATIS, in turn, may lead to decreased system reliability and accuracy. ATIS is unique in that the degree of consumer use affects system effectiveness. Thus, to optimize ATIS accuracy, initial acceptance of ATIS should be maximized.

The results of the study done by (Wochinger and Boehm-Davis 1997) indicate that the drivers showed strong differences in their initial preferences for maps and text directions. However, most of the participants rated ATIS higher than the other aids after a “hands on” experience with it. Older drivers in particular may be unlikely to embrace a technologically innovative system. An ATIS implementation strategy can facilitate user acceptance by presenting information to positively influence customer reaction to ATIS.

Giving drivers advance warning of an event can affect route choice and safety related factors such as driving speed. However, the success of such systems depends largely on the ability of drivers to assimilate, retain and act on the information received. These processes rely on the application of ergonomics to the design of the system's man-machine interface (MMI). So, it is very important to know how drivers assimilate information and retain it over time. (Graham and Mitchell 1997) carried out a road based experiment to examine both the assimilation process and the retention of information over time. Measures of recall performance and eye glance behavior were used to assess three factors associated with the design of driver information systems: the length of messages, the timing of messages, and driver age. The study compared the performance of two age groups of drivers using the system. Recommendations were made concerning the amount of information that should be displayed on the screen, the timing of messages in relation to events, and the presentation of message screens. (Akamatsu, Yoshioka et al. 1997) conducted field experiments to explore driver behavior and the processing of information when navigation systems are used in real urban areas. Driver behavior while using a navigation system in the central area of Tokyo was recorded by means of small video cameras, and the landmark information used by drivers was analyzed using the "thinking aloud" method. In the analysis, verbalized words were categorized into several types of landmark information.

Another important consideration is the amount of driver workload that is involved in using in-vehicle navigation or route guidance system. It is very important to know how the characteristics of route guidance systems affect the attentional demand and efficiency of the driving task and to understand how drivers react to complex route guidance systems under varying task demands resulting from driving in different types of roads. (Srinivasan and Jovanis 1997) used a high fidelity driving simulator to collect detailed driving performance data in an investigation of the following questions:

- do electronic route guidance devices lead to better driving performance compared to paper maps?
- do audio route guidance systems lead to better driving performance and lower workload compared to their visual counterparts and paper maps?
- does a head-up turn-by-turn display in combination with a head-down electronic route map lead to better driving performance and lower workload compared to a head-down electronic route map?

Its also important to know about drivers' route choice behavior in the presence of ATIS from human factors perspective. It might involve knowing drivers' behavior in the presence of different forms of information. (Katsikopoulos, Duse-Anthony et al. 2000) studied drivers' route choice behavior when travel time information is provided under varying degrees of cognitive load. In this study, travel time variability is presented by giving drivers a range of possible travel times for routes with an uncertain travel time. A route (main) with a certain travel time and a route (alternate) that could take a range of travel times are described. This study investigates the effects of average travel time and travel time variability. Scenarios were considered in which the average travel time of the alternative route was smaller than, equal to, and greater than the certain travel time of the main route. Attempts were made to determine whether the effect of range is a function not only of framing but also of the cost of being late. This research also tests whether participants make the same choices while driving as they do when sitting still.

4 NETWORK IMPACTS OF ATIS

4.1 From individual- to network-level impacts

Boyce (1988) speculated over a decade ago that as tripmakers begin to experience the benefits of better travel information and decisions from ATIS, they would come to re-consider and adjust many of their significant life decisions, including where they live and work, and how they arrange their daily activity schedules. Large-scale changes in residential and employment locations would inevitably lead to major shifts in urban, suburban and exurban land use and structure, affecting in turn the spatial pattern of transportation demand. Rearrangements in daily activity patterns – consolidating trips in to chains or splitting chains into individual trips, making trips at different times – would affect the temporal pattern of transportation demand. ATIS and related ITS technologies, he argued, were not just traffic information and management tools, but had the potential to affect travel demand at a fundamental level.

Clearly, significant rearrangements of the basic organization of peoples' activities, and the resulting changes in travel patterns, would have repercussions well beyond the transport sector: environmental and energy consumption changes, either positive or negative, would also follow, to cite only the most obvious.

Few analyses conducted to date have taken such a broad view of network-level ATIS impacts. Part of the reason for this, no doubt, is that there is very little empirical basis for quantifying the nature and magnitude of some of the effects identified by Boyce, Brand and others. In any case, most analyses are conducted within a short-term analysis time frame, and consider primarily the network effects resulting from route choice (occasionally route and departure time choice) adjustments by tripmakers in response to ATIS.

Clearly, the magnitude of network-level ATIS impacts depends on the number of drivers receiving information. If only a few drivers obtain guidance, they may benefit from improved decision-making, as discussed in Section 3.4, but any tripmaking changes they may make will have negligible impact on network conditions.

As more drivers receive ATIS messages, the aggregate effect of their reactions to it becomes important; indeed, because of the congestion externality, the aggregate effect may be out of proportion to the magnitudes of the individual reactions. This aggregate effect depends both on what particular guidance messages are disseminated (including where, when and to whom) as well as on how drivers react to the messages.

(Ben-Akiva, de Palma et al. 1991) identified some of the possible adverse network-level effects that can result from guidance dissemination. These include:[3]

- overreaction, which occurs when a significant number of drivers receive identical messages and react in roughly the same ways. This could cause congestion to transfer from one route to another or even produce oscillations in path flows; and

- concentration, which occurs when driver information reduces the natural variability of individual drivers' decisions and leads them to act similarly, possibly leading to congestion increases.

In either case, the distinct possibility exists that providing guidance messages could worsen rather than improve traffic conditions.

This means that as the number of drivers receiving guidance (the *market penetration rate*) increases, it becomes important when generating guidance to take account of the effects of the guidance itself on drivers and traffic conditions. This is necessary not only to avoid particular effects such as overreaction and concentration, but more generally to ensure that the guidance messages that are disseminated based on traffic conditions remain consistent with those conditions after drivers receive the messages and react to them.

Evaluations of network-level ATIS impacts can be categorized as theoretical (model-based) or empirical. Many, but not all, of these have focused on travel time and its variability, the measures most immediately impacted by ATIS. Examples of more general approaches to theoretical or empirical ATIS impact analysis follow.

(Thill and Rogova 2001) describe a sketch-planning model tool to screen proposed infrastructure-based ATIS projects (such as VMS) based on their improvements in travel delays, traffic safety and environmental quality. For VMS evaluation, for example, it assumes a basic corridor topology consisting of a main route and a diversion alternative. In case of an incident on the main route, it computes total time as the sum of time traversing the main route, time spent

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[3] They also identified the individual-level problem of oversaturation, which occurs when the amount of information a person receives is too great to be effectively processed into a rational decision in the time available to make the decision. The general problem of information oversaturation is exacerbated in a driving context because of the accident-producing potential of driver distraction or confusion. In practice, the need to avoid oversaturation limits the amount and complexity of information that can be conveyed in messages to drivers.

queuing there, time spent traversing the diversion route, and time lost when the diverted traffic merges with mainline traffic. Delay reductions are calculated by comparing total time in baseline and deployed situations. The basic traffic characteristics determined during the travel time calculations are used as inputs to the safety and environmental benefits estimates. Safety benefits (reductions in primary and secondary accidents, distinguished in terms of fatalities, injuries and property damage only) depend on the amount of congestion on the main and alternative routes. Environmental benefits (reductions in VOC, CO, NOx and fuel consumption) depend on calculated VMT and speeds. The evaluation tool utilizes default values for key parameters such as diversion rates, accident rates, and emissions factors, rather than computing them endogenously.

Brand (1998) (see also Brand 1995) argued that evaluation of ATIS economic impacts at the disaggregate level needs to take account of the many adjustments in the individual, household and business activities that would come about from improved travel information. These adjustments could generate considerable utility or economic benefits even if more trips were made and more time spent traveling. The nature of these benefits could best be determined by individual-level investigations (stated preference surveys in which ATIS users traded off alternative possible system features against possible costs), and the most accurate determination of system-level ATIS impacts would come from aggregating such individual level results. Indeed, he argues that considering only the total travel time or VMT impacts of ATIS might lead one to seriously erroneous conclusions regarding its benefits.

(Arnott, de Palma et al. 1991) also caution against simplistic measures of ATIS benefits. They argue that, since congestion is an un-internalized externality, drivers' reactions to information about congestion may not be efficient (in the economic sense). The reactions may increase rather than decrease congestion. The authors provide a simple model, involving route and departure time choice in a two-route corridor with stochastic capacities. They show that average travel costs are reduced when drivers receive perfect information about the route capacities; however, with imperfect information an un-internalized congestion, drivers may change their departure times in a way that worsens congestion.

Related points are made by (Emmerink, Nijkamp et al. 1994). ATIS may enable drivers to avoid excess travel from uninformed path choice decisions or parking search; on the other hand, because of the improved efficiency of travel, and the activity adjustments discussed in Brand (1998), ATIS may induce more demand for travel. They note that an ATIS may involve both positive and negative externalities: an additional ATIS-equipped driver will generally increase the travel times experienced by other equipped drivers, but will decrease the times experienced by unequipped drivers. The existence of these externalities may lead to market failure if not corrected. The authors suggest a combined system involving both ATIS and road pricing both to internalize the ATIS externalities and more generally to combat congestion.

The following section describes a number of selected model-based analyses of network-level ATIS impacts; as mentioned, most of them use travel time or related quantities as the principal measure of performance.

4.2 Conclusions from computational and analytical models

Model-based analysis of ATIS impacts may involve analytical (purely mathematical) or computational methods. In principle, analytical methods can provide exact solutions, but sometimes a problem has to be simplified to enable a solution to be determined. Computational methods allow greater latitude in representing problem features and assumptions, but it is sometimes difficult to derive general conclusions from the solutions obtained to particular problems or, sometimes, to know if a correct solution to a problem has been obtained at all.

(Al-Deek, Martello et al. 1989) used standard traffic simulation packages to determine travel times in recurrent and non-recurrent (incident) congestion conditions in a portion of the SMART corridor in Los Angeles, California. They also surveyed commuters in the corridor to determine their usual and diversion routes. The authors then compared path times on the usual and “optimal” (minimum travel time) paths for a number of OD pairs. The reasoning was that, under perfect information from an ATIS, drivers would pick the minimum travel time path. The analysis thus indicates the magnitude of travel time benefits that ATIS might produce in this corridor.

The results indicated that under the recurring congestion scenario, the travel time savings from utilizing the shortest path were generally negligible (less than 3 minutes for a 20-25 minute trip) compared to the travel time on other paths (usually the freeway-biased path). Under the incident congestion scenario, travel time savings from choosing the minimum time path were found to be significant (greater than 3 minutes) during certain times in the analysis time frame. The greatest time savings accrued during the time slices immediately following the incident occurrence, with a maximum savings of 10 minutes for a 30 minute trip.

Note that the analysis does not take account of the effects of the guidance itself on drivers’ decisions and the resulting traffic conditions. If a significant number of drivers switched paths in response to traffic information, travel times would no longer be the same as those used in the path time calculations and the “minimum” path found on the basis of the original times might no longer be so. This suggests that the estimated savings are upper bounds.

(Koutsopoulos and Lotan 1989) and (Hamerslag and van Berkum 1991) carried out studies of ATIS travel time impacts using a static stochastic user equilibrium assignment model. Informed and uninformed drivers were distinguished in terms of their travel time perception errors, modeled via the standard distribution of the error term in the probit-based path choice model. Informed drivers had small (possibly zero) error term standard deviations, signifying that their perceptions of travel times were close to reality; uninformed drivers were the opposite, and so, based on their inaccurate perceptions, might make path choices that were significantly sub-optimal.

In (Koutsopoulos and Lotan 1989), path choice was the only travel decision impacted by ATIS. They applied the model to a small urban area. They found that the difference in average travel times between informed and uninformed drivers (measuring the value of the information to the informed drivers) decreased as the network congestion level increased; however, informed users always had lower average travel times than uninformed users. With increasing percentages of informed users, the average travel time of both informed and uninformed users increased somewhat. Overall, however, the weighted average travel time decreased monotonically (but not always linearly) with increasing percentages of informed users.

(Hamerslag and van Berkum 1991) generalized the approach somewhat to allow trip distribution to depend on travel time perceptions. The authors used a combined static distribution-assignment model to predict the trip distributions and network traffic conditions that would result from different levels of information accuracy. The authors also considered a variety of networks. This is one of the few published quantitative studies of the possible impacts of ATIS on overall trip patterns (as opposed to path and departure time choice).

It was found that in all cases the total amount of travel (vehicle-kilometers of travel or VKT) decreased with decreases in the level of travel time uncertainty, as the spatial distribution of trips adjusted to the improved perception accuracy. The authors concluded that an ATIS might reduce VKT in urban networks by 15—20 percent and in regional networks by 5—10 percent.

The authors note that static traffic models that represent ATIS indirectly via its reduction in perception errors are not able to (i) analyze traffic dynamics at short or medium time scales or (ii) analyze specific ATIS characteristics or features.

(Al-Deek and Kanafani 1993) present an analytical queuing model of an idealized corridor with two parallel routes. An incident occurs on the main route. An ATIS diverts equipped vehicles to the alternate route in a way that maintains user-optimal travel times, based on moving and queuing, on the two.

The study results show that, following an incident, guided traffic is better off than unguided traffic during the diversion period that precedes the establishment of a travel time equilibrium between the main and diversion routes. However, this advantage is substantially reduced when a queue forms on the alternate route. The benefits to guided traffic are insensitive to the fraction of vehicles equipped with ATIS as long as this fraction is below the critical value that causes a queue to form on the alternate route.

When the alternate route is congested, the benefits to guided traffic become sensitive to the fraction of vehicles equipped with ATIS. The benefits to guided traffic decrease while the benefits to unguided traffic increase with this fraction. Thus, as the proportion of guided traffic increases, the difference in benefits between guided and unguided traffic narrows. System benefits increase proportionally with the market penetration rate as long as it is below the critical fraction, but increase less than proportionally when a queue forms on the alternate route.

(Emmerink, Axhausen et al. 1995) carried out studies of the travel time impacts of ATIS in a small network subject to random incidents, using a stochastic discrete-event simulator. Drivers were assumed to be boundedly rational, meaning that they only revise their current path if information that they receive about expected path times indicates the opportunity for a significant travel time gain. The authors investigated the travel time impacts of a number of ATIS parameters, including the market penetration rate and the information update frequency. The latter parameter determined how often updated estimates of remaining travel time to the destination (based on continuously changing travel conditions) were disseminated to drivers: periods of 1, 5 and 10 minutes were considered. Drivers receiving such information were assumed to combine it with their own prior experience to form their individual estimate, which was then the basis of a boundedly rational path switch decision.

The authors found that network-wide travel time decreased with increases in the market penetration rate. It was also found that the additional benefit to equipped drivers decreases quickly as the level of market penetration increases. Non-equipped drivers are also affected by the presence of equipped drivers, and their travel time benefits depend upon the level of market penetration as well. A decrease in the updating frequency has an adverse effect on network-wide performance. The size of this negative effect depends on the market penetration rate. However, the network-wide situation at full market penetration is still considerably better than without information.

(Mahmassani and Jayakrishnan 1991; Mahmassani and Peeta 1993) describe the Dynasmart simulation-assignment model developed at the University of Texas at Austin. Dynasmart is a mesoscopic traffic simulator, meaning that it simulates the movement of individual vehicles moving through a network in accordance with macroscopic flow rules (e.g., speed-density relationships.) It simulates several different route choice rules including dynamic system optimality, dynamic user optimality, and a bounded rationality rule in which drivers receiving en route information about path conditions will only switch paths if the expected improvement exceeds a threshold amount. Dynasmart has been widely used for investigations of route guidance. DynaMIT (Bottom, Ben-Akiva et al. 1999) is another mesoscopic traffic simulation model that is explicitly designed for route guidance applications.

(Hall 1996) reviews a number of simulation studies of ATIS total network-level travel time reduction benefits as a function of the ATIS market penetration rate. A number of these studies have found an “inverse U” shaped relationship, with maximum total benefits typically occurring at market penetration rates of 20—30 percent. Some have found negative benefits (i.e., increases in average or total network times) at high market penetration rates.

Using a simple analytical queuing model somewhat similar to the one applied by (Al-Deek and Kanafani 1993), he shows that for some network structures increasing the market penetration of accurate (i.e., experienced travel time) information cannot result in an increase in total network travel time; however, increasing the provision of instantaneous time estimates might in fact result in such an increase. He speculates that some of the results reported in earlier simulation and analytical studies may be due to use of instantaneous rather than experienced travel times in the models applied by their authors; this would lead travelers towards dis-equilibrium behaviors and produce disbenefits.[4] He argues that, in any case, the determination of the optimal market penetration rate is an irrelevant issue, since the rate should be determined through market forces and not enforced by policy fiat.

Hall's paper also highlights the importance of developing accurate models of traveler response to information for generating guidance and predicting its network-level impacts.

Finally, it argues strongly against attempting to manipulate ATIS messages (restricting or misrepresenting information) in an attempt to manipulate driver behavior towards some "social engineering" objective. Rather, he argues, ATIS should be viewed first as a service to the public, to improve their confidence and comfort in using the transportation system, and second as a means for steering traffic away from dis-equilibrium behavior and towards user optimal travel patterns that utilize alternate routes where feasible.

4.3 Conclusions from operational tests

With the possible exception of a few VMS-based ATIS in high volume corridors, operational experience to date with ATIS has been on too limited a scale and for too brief a time to be able to draw strong and broadly applicable conclusions regarding its network-level impacts.

Potential users have not had sufficient time to become aware of and comfortable with ATIS, and to integrate it into their travel decision-making processes. For this reason, among possibly others, the utilization of prototype deployments has generally been at low levels. The deployments themselves have usually been limited in capabilities, in time, and frequently also in geographic scope. Thus, the network-level impacts they have produced have often been small and difficult to measure, even when their impacts are more evident at the individual or (sometimes) corridor level.

[4] It is also possible that these studies made driver behavior assumptions that are not fully consistent with an equilibrium framework.

Some network-level ATIS evaluation studies have carried out their work in an indirect way. Rather than attempting to measure the impacts directly, they proceed by obtaining what (little) empirical data on impacts might be available, completing the data with default values and assumptions as required, and using the resulting data set as input to a traffic or economic evaluation model. The model then extrapolates the limited data to the full network level and computes the impacts.

This may be a reasonable approach until larger-scale ATIS deployments become common. It implies a well-defined and focused data collection effort tailored to producing data useful for such an approach, as well as network-level models capable of representing ATIS.

(Yim and Miller 2000) describe the evaluation of the two-year TravInfo field operational test by the California PATH program's Institute of Transportation Studies. TravInfo's goal was to broadly disseminate accurate, comprehensive, timely and reliable information on traffic conditions and multi-modal travel options to the public in the San Francisco Bay Area. To this end, it established a Traveler Advisory Telephone System (TATS), to which users could call for up-to-date information on travel conditions and options, as well as a web site displaying real-time traffic conditions. The evaluation considered the operational test from a number of viewpoints, including institutional, technological and user response.

With respect to user response, surveys showed that less than 10% of Bay Area households were even aware of TravInfo's existence or features and, of those who know about it, very few had actually tried it. Those who did use it, however, found the services to be useful for trip planning and reported high levels of satisfaction. TravInfo was able induce some users of radio and television traffic reports to switch, and also to to capture some people who had never before used radio or television reports. Roughly half of the TATS callers, and more than three-quarters of the website visitors reported altering their trips after obtaining information about their routes. By the end of the operational test, around 5 percent of users were asking about transit options and, of those, 90 percent reported using transit for their trip. Overall, however, the report concludes that TravInfo's impact on the transportation system was marginal.

(Lee 2000) presents a framework for the benefit-cost evaluation of Seattle, Washington's Internet-based freeway management system, called FLOW. Among other things, FLOW maintains a web site that displays a color-coded real-time prevailing traffic conditions on expressways and major arterials at the segment and lane level; data is updated every two minutes.

Very little data was available on the impacts of the FLOW system: mostly individual-level results from wave 7 of the PSRC survey and from an MMDI survey. Lee supplemented this data with default and assumed parameter values to estimate the economic benefits of different system impacts on different types of user. It expanded these to the total user population, and compared the resulting total benefits with a rough estimate of the system costs. The specific conclusions reached are perhaps not extremely reliable, given the many assumptions that were required to reach them. The interest and value of this paper is in providing an evaluation framework and methodology, and in indicating the types of data that would be required to carry out a more accurate evaluation.

The framework distinguishes five market segments by trip purpose, using purpose as a proxy for travel information needs and likely behavioral response. It also characterizes people as auto users, transit users and non-captives. The responses to information that are considered are: change mode; add trip; delete trip; change destination; change route, change departure time; change confidence level; and nothing.

Impacts of each of these response types are characterized as internal (to the traveler) or external (to others), and are evaluated; each response may entail a number of impacts of both categories.

Evaluation of internal impacts depends on whether the response is primarily motivated by consideration of travel times (as in route choice) or not. If so, travel time savings are estimated and converted to monetary equivalents. Otherwise, the paper suggests estimating the consumer's surplus change of the (possibly complex) response, using willingness to pay estimates from stated preference surveys.

External impacts are computed as the difference between marginal and average costs. Changes in modal VMT are used to compute external emissions costs, while changes in travel time are used to compute external congestion costs.

Computing benefits in this way, making assumptions about their change over time, and comparing the total benefits with rough estimates of system costs, Lee estimated that the benefit/cost ratio of the FLOW system was 2.0, with a range of uncertainty between 0.5 and 3.0.

(Wunderlich, Bunch et al. 2000) describe their model-based evaluation of the SmartTrek Seattle MMDI, involving ATIS (a variety of traffic information services) and ATMS (traffic signal coordination) measures in a freeway/arterial corridor north of the Seattle CBD. The evaluation focused on project impacts that are difficult to evaluate with direct field measurements because of their magnitude or geographic dispersion, or because of the presence of confounding factors.

The evaluation used both a conventional four-step transportation planning model (EMME/2) as well as a traffic simulator (INTEGRATION) that can use some planning model forecasts as inputs. The conventional model was used to identify regional-level impacts on travel demand patterns, while the simulation model was applied to identify ITS impacts under dynamic traffic conditions. Models were validated against corridor traffic counts and travel time measurements.

The simulation was applied to a series of scenarios representing combinations of traffic demand variations, weather conditions, and patterns of incidents. Each scenario has a weight, or probability of occurrence. The scenarios taken together comprise a representative year of system operation.

Different levels and combinations of ATIS and ATMS capabilities were tested against a baseline scenario. Evaluation measures included subarea and regional impact variables. Variables included delay reduction, throughput, traffic condition variability, VKT of travel, fuel consumption, pollutant emissions, mode shares, trip lengths and speeds.

5 MODELING THE NETWORK IMPACTS OF ATIS

This section discusses the modeling of ATIS and the prediction of its impacts on traffic flow patterns and conditions, within the framework of static and dynamic traffic network models.

Much of the literature reviewed in the preceding sections is concerned with the response of individual tripmakers to travel information; as the review indicated, the state of knowledge on this subject is still far from complete. Suppose, however, that very good models of individual tripmaker response to ATIS were actually available, so that it would be possible to accurately predict the departure time, destination, mode and/or route that a particular tripmaker would choose if he or she were to receive a particular set of information from an ATIS. Suppose, also, that many tripmakers received ATIS guidance. What then would be the overall effect on network flows and travel conditions resulting from the aggregate response of the individual tripmakers to the travel information that they received? Might the changes in flows and conditions be sufficiently large as to affect the travel information provided by the ATIS? And if so, how should the provided travel information account for tripmakers' responses? These questions are important if our knowledge of individual traveler response to information is to be usefully applied to improve network-level operating conditions, or to generate effective predictive guidance (see section 1.1).

Answering these questions requires a transportation network model that is capable of:

- adequately representing the technical and information characteristics of specific ATIS deployments as they affect tripmaker response and network impacts;

- accurately predicting tripmaker responses to received ATIS messages (as well as the travel decisions of those who do not receive ATIS messages); and

- translating predicted individual-level tripmaker behavior into the network-level travel flows and conditions that result from them.

Few if any current transportation network modeling packages can carry out these tasks in a direct fashion. Many current approaches to modeling ATIS in a network context utilize a two-phase approach. In the first phase, a transportation situation is analyzed using a conventional network model that does not represent ATIS services, and does not attempt to predict their effects on individual travel behavior or network-level traffic patterns and conditions. A post-processing adjustment of the conventional model outputs is then performed to account for the impacts of ATIS. This approach is typified by the IDAS (ITS Deployment Analysis System) software package. (IDAS is also able to analyze ITS technologies and services other than ATIS.)

The advantage of such approaches is that they do not require changes to currently used traffic modeling software and so can be applied immediately; IDAS, for example, can directly post-process outputs from a variety of commercially available software packages. On the other hand, the two-phase approach carries the risk of introducing inconsistencies between the procedures used in the conventional model and those applied in the post-processing stage. It would be preferable to accommodate ATIS fully and consistently within the framework of the network model system itself.

Some model systems have begun to do this. Both the DYNASMART-X system (developed at the University of Texas at Austin under the direction of Prof. Hani. Mahmassani) and the DynaMIT system (developed at the Massachusetts Institute of Technology under the direction of Prof. Moshe Ben-Akiva) incorporate travel information in some form in their network modeling. These systems are mesoscopic traffic simulators that build on the traditions of traffic network simulation modeling but add significantly to these traditions by incorporating features such as sophisticated driver choice modeling, dynamic OD matrix estimation, and others. Both are under continual development, and are ultimately intended for deployment and real-time use in an operational traffic information center. (A few commercially-available traffic simulation systems also incorporate information in their network models. Unfortunately, the suppliers of these systems are sometimes reluctant to provide detailed descriptions of the assumptions, methods models and algorithms incorporated in their software. For this reason these systems are not considered here.)

DYNASMART-X and DynaMIT incorporate many reasonable design decisions regarding the representation of travel information, the modeling of traveler response to information, and the incorporation of these ATIS aspects in a network model. However, it is fair to say that these design decisions were not made from the perspective of a fully general framework for incorporating travel information in network models. This comment is not intended as a criticism of either model. A general framework for network-level modeling of travel information did not exist at the time the software was being written. Moreover, the development of such a framework was not a high priority for either project; their primary concerns centered on the creation of very large yet reliable and efficient software systems for traffic simulation.

This situation can be compared, in some respects, to the evolution of conventional static network modeling approaches and software from early efforts to the present status. Traffic network modeling software developed during the late 1950s and throughout the 1960s was based on heuristics – reasonable-seeming methods that usually appeared to work efficiently and to give believeable results, but that could not be proven to be correct. This was so despite the fact that, in the 1950s, (Wardrop 1952) had clearly defined the notion of a traffic user equilibrium, and (Beckmann, McGuire et al. 1955) had formulated the equilibrium assignment problem as a well-posed optimization problem. However, it was not until the work of (LeBlanc, Morlok et al. 1975) that a rigorous and efficient algorithm for solving Beckmann's equivalent optimization problem was published, and software implementing provably correct solution methods became available. (As it turned out, some of the heuristics that had been developed were very similar to the rigorous solution method of LeBlanc et al., sometimes differing only in a single trivial step such as a line search.)

Thus, while the particular information modeling approaches adopted by projects such as DYNASMART-X and DynaMIT seem reasonable, there is benefit in attempting to develop a more general framework applicable to modeling network-level information impacts. The framework may suggest alternative modeling or solution approaches that, on examination, prove to be advantageous in some respect. At a minimum, the general perspective offered by the framework will provide a better appreciation and understanding of the particular design choices that were made during the development of existing modeling systems, and guidance for the development of new systems.

We propose here a high-level framework that might be suitable for this purpose. To this end, the following sections review the conventional transportation network modeling framework, highlight the difficulties encountered in applying this framework to ATIS modeling, and show how these difficulties can be resolved.

5.1 The conventional transportation network modeling framework

5.1.1 OVERVIEW

Entire books have been devoted to transportation network modeling (Sheffi 1985; Thomas 1991; Ortuzar and Willumsen 1996; Cascetta 2001), and it is not the objective here to duplicate them or to provide an exhaustive description of the current state of network modeling practice. Rather, the intent of this discussion is to briefly summarize the principal aspects of the conventional transportation network modeling framework, highlighting particular features that either lend themselves to or conflict with the needs of ATIS modeling.

Transportation network travel forecasting is an application in a network structure of the economic paradigm of supply-demand interaction leading to equilibrium. Given a description of network infrastructure and operational characteristics that supply transportation service, and of the land use and activity patterns from which travel demand is derived, transportation network modeling attempts to predict the demand flows and the network conditions that result from the supply-demand interaction over a particular analysis time period. Frequently, interest focuses on predicting the steady-state conditions that prevail over a period of time (e.g., a peak hour or peak period) that is long relative to the time scale of flow dynamics (e.g., the time taken by individual vehicle maneuvers such as lane changing, turning movements, or queuing); models that address this question are known as *static* transportation models, and software that implements them is widely available. More recently, interest has grown in replicating and predicting the variations in traffic flows and conditions at much finer time scales (for example minute by minute); models that address flow phenomena at this level of temporal detail are called *dynamic* transportation models. Most existing software packages for dynamic transportation modeling are research oriented, although commercial packages are beginning to appear.

Traditionally, network forecasting is carried out using the so-called *four-step process*, which consists of the following high-level operations:

- trip generation: determining the total number of trips produced by each origin traffic analysis zone (TAZ) and attracted to each destination TAZ in a study area over a particular analysis time period (for example, the peak hour);

- trip distribution: given the production and attraction totals computed during the trip generation step, determining the total number of trips traveling between each particular origin and destination zone pair (referred to as an OD pair);

- mode split: given the total number of trips between each OD pair, determining the number of trips made on each mode serving each OD pair. (This step may be omitted when analyzing situations where changes in mode shares are unlikely to be important); and

- assignment: given a fixed set of trips routing themselves through the modal (e.g. road or transit) networks from origins to destinations, determining the resulting volumes and travel conditions on network links (individual facilities).

There are numerous variations on the process. Frequently trips are distinguished by their purpose, and the generation, distribution and mode split steps are carried out separately for each distinct purpose (all trip purposes are aggregated in the assignment step, however). Some applications perform mode split before trip distribution. Others attempt to represent the choice of trip departure time, and so may shift travel demand from one analysis time period to another. Yet others incorporate a step that forecasts TAZ-level land use and activity patterns prior to trip generation.

Regardless of the details, however, the four-step process is fundamentally sequential, with each step proceeding to completion and providing its outputs as the inputs to the next step. Possible influences of later steps on earlier ones (in particular, the effects of travel conditions determined during traffic assignment on trip productions, attractions, distribution and/or mode split) are either ignored, or are accounted for via “feedback”: iterative execution of the entire sequence of steps using, in a given iteration, assignment step results from prior iterations (possibly with modification) as input to that iteration’s trip generation, distribution and/or mode split steps. The iterations are continued until some convergence criterion is met or a pre-specified computing effort is expended.

Note in passing that there is no intrinsic need to apply a sequential rather than a simultaneous approach to network forecasting. Indeed, unless “feedback” between the steps is performed correctly, use of a sequential approach may lead to incorrect model solutions (COMSIS 1996; Miller 2001). Numerous studies have shown how the trip generation, distribution and mode split steps (or some subset of these) can be integrated with the traffic assignment step in an extended model and correctly solved, but these results have not been widely applied in the transportation planning community, and few commercially available software packages for the static problem adopt this approach. In contrast, software for the dynamic problem tends to incorporate greater simultaneity between steps.

We will concentrate here on traffic assignment for road networks. Many of the major network effects of ATIS are captured in this step. Furthermore, of the four steps in the conventional model system, traffic assignment has arguably received the most thorough study, has achieved the greatest amount of consensus on valid approaches, and has been the most generally systematized in its implementation details (at least in static models). As a result, the discussion here can consider in some detail the standard methods for traffic assignment, and the modifications to them that are needed to incorporate ATIS in assignment. Because of the wide variety of approaches commonly applied to the other steps of the four-step process, a comparable degree of specificity is not possible with them. However, by focusing only on traffic assignment, we do not take account of the possible effects of ATIS on total tripmaking, destination choice, mode choice and trip departure time decisions, or consider network impacts of transit information systems. These effects can be handled by extending (but not fundamentally changing) the road network ATIS analysis framework that will be presented below.

5.1.2 STATIC TRAFFIC ASSIGNMENT

Given a demand for road travel between origin and destination zones over a particular time period, traffic assignment determines the link-level traffic volumes and conditions that result from the path choices made by the OD trips. In static traffic assignment, each OD pair’s demand is assumed to remain at the same level throughout the duration of the analysis time period, and the objective is to determine the resulting steady-state (i.e., time-invariant) link volumes and conditions that prevail during that period.

A traffic assignment model incorporates three basic components:

- a path choice model;
- a network loading procedure; and
- solution logic that initializes variables, invokes the path choice and network loading components with appropriate inputs, iterates as needed, and decides when the assignment process is complete.

Path choice models used in conventional traffic assignment models are based on economic utility theory: they assume that a tripmaker at the origin chooses, from among a set of considered paths to the destination, the path that is perceived to have maximum utility. However, different path choice models vary in their assumptions with regard to:

- how path utility is quantified. Usually path *dis*utility (to be minimized) is represented as travel time, travel cost, or some weighted combination of the two;
- how tripmakers perceive path utility; and
- how tripmakers identify the set of possible paths to consider.

Deterministic path choice models represent the path choice decision as if tripmakers have perfect information about network conditions when they are considering their path options at the origin. (For convenience of expression, the following discussion will frequently use travel time as a proxy for a more general definition of network conditions.) The available information is assumed to be completely accurate, correctly perceived, and to correspond exactly to the utility that tripmakers take into account when choosing a path (for example, travel time or cost minimization.) Tripmakers are assumed to consider all possible paths connecting their origin with their destination, and always to choose the path that has the highest utility (or least disutility) value. (If there are several such paths, any one may be chosen.) Standard minimum path algorithms are used for this purpose; they are able efficiently to determine the shortest (i.e., minimum disutility) path in a network without explicitly examining all possible paths.

In *random utility* path choice models, the utility of a path is represented as a random variable, usually specified as the sum of two terms: (i) a systematic (deterministic) utility similar to that used in deterministic models; and (ii) a zero-mean random disturbance having some given probability distribution. The disturbance term may represent imperfect perception of network conditions by the tripmakers; alternatively, it may derive from fundamental modeling limitations, such as the inability to capture in a model all of the personal considerations that enter into a tripmaker's path choice decision for a given trip. In either case, the disturbance reflects uncertainty with respect to the path choice decision made at the origin. Thus, although tripmakers are assumed to choose the path that provides maximum utility to them, the randomness of the utility specification prevents us from knowing with certainty which path that will be. Instead, we can only determine the *probability* that each of the different considered paths will be chosen: this can be computed from knowledge of each path's systematic utility, and the joint probability distribution of those paths' random disturbance terms.

It is neither behaviorally realistic nor computationally feasible to consider all possible paths in a network and compute a choice probability for each. Therefore, random utility path choice models generally apply some path pruning rule to select the paths that will be considered. These might involve a path efficiency criterion (requiring, for example, that each successive link on a path leads farther away from the origin), or generation of a small set of paths "on the fly" (i.e., in successive iterations of the assignment process), or *a priori* selection of a set of allowable paths.

Note, too, that some methods based on random utility path choice, such as the STOCH algorithm (Dial 1971), define the path choice set and determine the path choice probabilities in an implicit rather than an explicit fashion, by computing the probability of choosing each link exiting from each successive node in the set of efficient paths. However, the ultimate effect is the same as if the choice probabilities of efficient paths were being computed: given a specific path, its choice probability can be computed in a straightforward way.

After the path choice decisions are made, the traffic assignment process *loads* the corresponding trips on the selected path(s). Static network loading consists of:

- determining the part of the total OD flow that will use each of the available paths. The way in which this determination is made depends on whether a deterministic path choice model was used to identify a single path, or a random utility path choice model was used to compute the path choice probabilities of each of a set of paths. In *deterministic* loading models, all of the OD flow is loaded on the one selected path. In *stochastic* loading models each available path receives a part of the total flow, according to its probability of being chosen. (Again, in some loading procedures such as STOCH, the path flows are determined implicitly in terms of the flows exiting each node via each of the outgoing links;)

- propagating the path flow over each link on the path from origin to destination, and determining the resulting link flows. In static models, which consider only steady state conditions over the analysis period, the time required for flow to propagate from one link to the next, and the fluctuations in link volumes as flow traverses them, are not taken into account. The flow on each link is computed by accumulating the steady state flow contributed by each path that goes through the link; and

- updating link conditions based on the accumulated link flows. Any of a variety of relationships – generically known as link performance functions – may be used for this purpose. Link performance functions capture traffic congestion effects. Link condition updating is generally carried out after the flows from all OD pairs have been processed; it utilizes the final link volumes.

The path choices that are used in loading derive from a set of network conditions, yet these conditions may change as a result of the loading. Consequently, loading may invalidate the earlier path choice decisions: the path that was thought to be optimum in a deterministic model is no longer so, or the path choice probabilities computed from a random utility model no longer correspond to the new conditions.

All traffic assignment models attempt to enforce a system-level *consistency* requirement: after the assignment procedure determines tripmakers' path choices, loads them on the network and updates link conditions, the updated conditions should not cause a revision of the path choices. In *deterministic user equilibrium*, the paths that were thought to be minimum should remain so after the loading; and in *stochastic user equilibrium*, the path choice probabilities that were used for the loading should equal the probabilities that are determined from the updated conditions. The term *user equilibrium* originally relates to the definition by (Wardrop 1952) of the requirement that, in a deterministic path choice model, the paths that are chosen by travelers should all have equal travel times, and this time should be less than or equal to the travel time on any path not chosen. The term was later extended to cover user equilibrium in situations of stochastic choice as well. Although user equilibrium is not commonly referred to as a consistency requirement, in fact it is one. Inconsistency occurs when travelers choose a path thinking that they will encounter certain travel conditions, only to find that the conditions are actually different from what they expected; they would thus have cause to revise their path choice, so the original choices and conditions could not have been in equilibrium.

A fairly natural way of expressing an equilibrium condition in mathematical terms is as a fixed point equation. The following paragraphs explain this idea, which, as will be seen, generalizes in a fairly straightforward way to network modeling with ATIS.

Let f be a mathematical function mapping inputs x from a set X to outputs y in a set Y. We write $f: X \rightarrow Y$ to show the relationship of the function to its input and output domains and $y = f(x)$ to show the output value corresponding to a specific input value. Suppose that the input and output domains are the same; the function maps one value to another in the same domain. We say that a value x^* is a fixed point of the function f if $f(x^*) = x^*$; in other words, a value x^* is a fixed point of a function if, when it is supplied to the function as input, the function returns the same value as output: the function maps x^* to itself. A function may have zero, one, or multiple fixed points. To compute a fixed point of a function (if one exists), it suffices to solve the equation $f(x) - x = 0$ using any suitable root-finding method.

Suppose C denotes the set of possible link conditions, and P is denotes the set of possible path choice probabilities. A path choice model, regardless of how complex it may be, is simply a function D that takes inputs C and produces outputs P; we can write D: $C \rightarrow P$. Similarly, for a given fixed OD matrix, a network loader S, regardless of its details, is simply a function that takes inputs P and produces outputs C; we can write S: $P \rightarrow C$. The functions D and S are simply symbolic representations of whatever operations these two models carry out to transform their respective inputs into outputs.

For some path choice and loading models, the functions D and S can be written down mathematically if required; for others, the functions have no straightforward mathematical expression, and are defined only in terms of their algorithmic specification or software implementation. In either case, however, it is both possible and convenient in the discussion here to treat these models as "black boxes", ignoring their internal details and focusing only on their inputs, outputs and interconnections.

These two functions can be put together ("composed") in either of two ways. For example, if we start with a set of path choice probabilities p1, we can input these to the network loader to obtain the resulting set of traffic conditions c1 = S (p1). We can then use these output conditions to compute the resulting path choice probabilities p2 using the path choice model p2 = D (c1). If the "input" path choice probabilities p1 equal the "output" path choice probabilities p2 then, as was discussed above, p1 (or equivalently p2) represent user equilibrium path choices. The composition of the two functions in this order is written p2 = D°S (p1), which means: use p1 as input the to function S, then use the resulting outputs of S as inputs to the function D, calling D's outputs p2. From the discussion, it can be seen that equilibrium path choice probabilities are a fixed point of the composite function D°S: $P \rightarrow P$.[5] An equilibrium set of path choice probabilities p^* satisfies the fixed point equation $p^* = D°S\ (p^*)$.

Similarly, if we start with a set of conditions c1, we can use the path choice model to predict the corresponding path choice probabilities p1 = D (c1), and can then input these probabilities to the network loader to obtain a new set of conditions c2 = S (p1). If the "output" conditions c2 equal the "input" conditions c1 then, by reasoning similar to that presented above, c1 (equivalently c2) represent equilibrium network conditions, and these conditions are a fixed point of the composite

[5] This statement is exactly correct for stochastic user equilibrium, but must be slightly modified for deterministic user equilibrium. The issue is that, in the latter case, there may be several minimum paths at equilibrium, with some carrying traffic and others not. Thus, two equilibrium solutions may entail different path choice probabilities. This situation can be handled by a generalization of the fixed point concept to point-to-set maps. It is likely, however, that deterministic user equilibrium will not be widely used in ATIS modeling because it would imply, for example, that drivers will comply fully with route recommendations – a highly questionable assumption. Probabilistic models and stochastic user equilibrium (or its generalizations, discussed below) would seem to be more appropriate in ATIS modeling contexts. Thus, while the issue of non-unique paths in deterministic equilibrium must be carefully addressed in theoretical discussions, it is unlikely to be of much significance in practice.

function $S^\circ D: C \rightarrow C$.[6] An equilibrium set of link conditions c^* satisfies the fixed point equation $c^* = S^\circ D (c^*)$.

In the past, the principal application of fixed point equilibrium formulations has been to analyze theoretical properties of equilibrium flow patterns (see, for example, (Braess and Koch 1979)). They were rarely the basis for developing assignment algorithms, in part because of concerns over their computational efficiency and (for the path-based formulations) their computer memory requirements. Recently, however, Cantarella (1997), building on earlier work by Daganzo (1983), derived two separate fixed point formulations, in terms of link costs and link flows, for very general versions of the static traffic assignment problem, and showed that a simple algorithm called the MSA (discussed below) could be used to solve them.

Apart from its expression as a fixed point equation, the equilibrium consistency requirement has various other quantitative implications. In the case of deterministic assignment models, for example, one implication of the consistency requirement is that at equilibrium, for a given OD pair, conditions on all paths used by tripmakers are equal, and these conditions are better than or equal to those on any paths that are not used; as noted above, this is called Wardrop's ((Wardrop 1952)) principle. In the case of stochastic models, the quantitative implications require equality of the path choice probabilities or of link flows or conditions before and after loading. Consistency conditions such as these can be used as a basis for computing traffic network equilibrium or for checking a tentative solution.

Various mathematical formulations of traffic network equilibrium problem can be derived and their solutions shown to imply the equilibrium conditions. By far the most widely used of these are formulations as optimization problems. Half a century ago, Beckmann (1955) devised an optimization problem whose solution conditions imply the Wardrop principle for networks with a simple form of link performance function (i.e., one for which the traffic conditions on a link depend only on the total amount of traffic using that same link). Most current traffic network software packages compute deterministic equilibrium indirectly, by solving Beckmann's equivalent optimization problem using any of a variety of nonlinear optimization algorithms.

Similarly, Sheffi and Powell (1982), building on other earlier work by Daganzo (1979), formulated an optimization problem whose solution conditions imply the stochastic network equilibrium conditions. They identified a stochastic approximation algorithm that had been developed in the early 1950s, originally by Robbins and Monro and later by Blum, as being well-suited for solving their optimization problem, and named their version of this algorithm the method of successive averages (MSA). Most current software packages compute stochastic equilibrium by solving Sheffi and Powell's equivalent optimization problem (or special cases of

[6] The issue mentioned above for deterministic user equilibrium in path choice probability variables does not arise when condition variables are used. Thus, if DUE is used as a modeling principle, it will be easier to work with the $S^\circ D$ fixed point formulation.

it that result when particular path choice models are used), applying the MSA or other optimization algorithms for this purpose.

In both the deterministic and the stochastic cases, the optimization algorithms call on the path choice and network loading procedures to carry out particular computational subtasks required as part of the solution process. The algorithm implements the logic that determines the inputs that these procedures are invoked with, executes them, and ascertains if an equilibrium solution has been reached; if not, it continues with an additional iteration.

The MSA, for example, consists of the following steps when applied to solve for link cost traffic equilibrium conditions:

0:	c_0 = free-flow link costs; $k = 0$	*initialize*
1:	$p_k = D(c_k)$	*get path splits based on current link costs*
2:	$d_k = S(p_k)$	*get auxiliary link costs based on path splits*
3:	if convergence is achieved, stop	*if converged, c_k is the solution; else continue*
4:	$k = k+1$	*bump iteration counter*
5:	$c_k = c_{k-1} + (1/k) * (d_{k-1} - c_{k-1})$	*update link costs*
6:	go to step 1	*iterate*

The prototype version of this algorithm was originally developed to find the roots of functions whose evaluations return values tainted by noise; it can be mathematically proved to converge to a correct root value, under certain conditions on the involved function. Sheffi and Powell (1982) showed that these conditions are met when the method is applied to solve their equivalent SUE minimization problem, so for this problem it is a verifiably correct method.

The method has also been applied, however, to problems for which no convergence proof is available. It seems to work well on a wide range of problems, including even completely deterministic problems in which no noise is present. It does not require information about the mathematical properties of the involved functions (the only operation is function evaluation). It is very robust and simple to implement. Note, too, that one path split model could be replaced with another, or one network loader with another, without affecting the overall logic of the algorithm.

On the other hand, the lack of convergence proof for general applications is worrisome, and its computational efficiency is often disappointing: frequently, after achieving rapid progress in the first few iterations, it then slows down considerably and makes increasingly small improvements from one iteration to the next. The measurement and detection of convergence can also be delicate: it is not sufficient to compare two successive iterates (for example, c_k and c_{k+1} in the listing above) since, by the nature of the algorithm, they will tend to be closer and closer together as the computation progresses. A natural convergence measure, in the context of fixed point problems, is the distance between an estimate and its image through the map of interest; in the example given above, the distance (suitably defined) between c_k and d_k = S°D (c_k). At a fixed point this distance would, of course, be 0. Even if some other convergence measure is used, verification of the fixed point condition after the algorithm has terminated is a direct way of checking the computed result when a rigorous convergence proof is lacking.[7]

Despite these issues, the MSA has been applied as a heuristic (i.e., a non-rigorous computational method that seems to work well in practice) to a wide variety of transportation problems, including the "feedback" operation in the four-step process, the dynamic network loading problem, and the dynamic traffic assignment problem, discussed below.

There are other mathematical formulations of the network equilibrium problem. One intensively studied formulation is as a variational inequality problem. The equivalent variational inequality formulation can be shown to imply network equilibrium conditions for very general link performance relationships, and so is more broadly applicable than the equivalent optimization formulation. In practice, however, the most commonly used link performance functions are of the simple form assumed by Beckmann and by Sheffi and Powell, so this added generality is not often needed in practical modeling work, and few commercial software packages compute traffic network equilibrium utilizing this approach.

5.1.3 DYNAMIC TRAFFIC ASSIGNMENT

5.1.3.1 Overview

Static network models have been used for over forty years in practical transportation network planning. Typical planning applications, concerned as they are with problems such as infrastructure project evaluation or meso-scale environmental quality analyses, do not usually need to consider the detailed dynamics of variations in traffic flows and conditions over short- and medium-term time frames, or transient traffic phenomena such as queue build-up and dissipation. More recently, however, there is increasing interest in being able to understand and predict dynamic (time-varying) features of traffic flow in networks, in part because of the importance of these capabilities for developing and operating real-time traffic management and information applications. Static models are not able to provide this level of temporal analysis detail. A different type of assignment model, called a dynamic traffic assignment (DTA) model, is required to represent the variations of traffic phenomena over time.

[7] This test is less straightforward when, as is the case in some stochastic user equilibrium models, function evaluations return values affected by noise; in such a case, the distance between c_k and S°D (c_k) would generally be positive even if c_k were a fixed point.

This section considers DTA models as dynamic generalizations of the static models discussed above; this is the conventional usage of the term. Like static models, they incorporate a representation of tripmakers' path choice decision-making logic; include a network loader to propagate trips along the selected paths; and attempt to compute an equilibrium state involving consistency between network conditions and path choices. Furthermore, they assume that travelers have access to perfect information prior to setting out on a trip; they thus make a path choice decision at their origin and follow it through to their destination. (Clearly, such assumptions are not appropriate for modeling traveler information. Modifications to the conventional DTA modeling approach required to handle network-level impacts of traveler information are discussed in section 5.3.)

Although DTA models have similarities with static assignment models, there are also many important differences between the two. In dynamic models all variables are functions of time. Time may be represented as a continuous variable, or alternatively be discretized into finite duration time steps (ranging from fractions of a second to many minutes in length, depending on the desired temporal precision and the level of detail of the modeling relationships). OD demand rates may change from instant to instant, leading to surges or lulls in the amount of traffic entering the network. Similarly, the amount of OD traffic departing at each instant on the various available paths will change because of changing network conditions or randomness in driver behavior. Traffic may be represented as individual vehicles or vehicle "packets" (in simulation-based DTA models), or as flows or flow packets (in analytical models). As the traffic works its way along its chosen paths through the network, link traffic volumes and conditions will be affected by its passage and so also will change with time.

(In dynamic traffic models, the reference time for describing a time-varying phenomenon is, by convention, taken to be the time at which the phenomenon *begins*. For example, if we say that a particular link's traversal time is one minute at time t, we mean that vehicles that *enter* the link at time t will take one minute to traverse it.)

5.1.3.2 Path choice models

Because traffic conditions are functions of time in dynamic models, there is a greater variety of possible path choice model assumptions than is the case in static models. For example, the travel time required to traverse a path from origin to destination, as a function of the time of departure from the origin, can be defined in at least two different ways: as the sum of the traversal times of all the links on the path at the time of departure from the origin, or as the sum of each link's traversal time at the time the vehicle actually enters it. The former definition is called the *instantaneous* path time; it is based on a "snapshot" of the network conditions prevailing at the time of departure from the origin. The latter is called the *experienced* path time; it is the time that would actually be taken to traverse the path by a vehicle departing from the origin at that moment. (Note that the term *experienced* does not imply that the driver actually must travel on the path to learn its attributes.) Instantaneous conditions are easier to compute, but experienced conditions correlate better with what a trip encounters in its passage through the network.

The path choice component of a DTA model could involve either instantaneous or experienced travel time variables, depending on the data available with which to estimate the model, and the particular assumptions appropriate for the application. Nonetheless, in deterministic DTA models the path choice decision is represented as if drivers correctly perceive the (instantaneous or experienced) network conditions, while in stochastic DTA models the path (dis)utilities include a random disturbance term – just as in static assignment models. Like static models, DTA models assume that all information relevant to the path choice decision is available to tripmakers at their origins, prior to beginning their trips; similarly, DTA models assume that once tripmakers have chosen a path at the origin, they follow it unswervingly to the destination.

5.1.3.3 Dynamic network loading models

Recall that, in static models, the detailed changes in flows and conditions that occur as traffic propagates from link to link along its chosen path are not taken into account since these are transient rather than steady state phenomena. However, in dynamic models these variations are precisely the outputs of interest. The *dynamic network loader* allocates given fixed OD flow totals across the available paths in accordance with given path probabilities, then moves the resulting path flows from link to link along the OD path, simultaneously determining the resulting dynamic link flows and conditions. Network conditions determine the amount of advance per time step on each link and from link to link; conversely, network conditions are themselves determined by the dynamics of traffic propagating along its paths.

Dynamic network loading is considerably more complex than static network loading because it needs to track the progression of path flows from link to link over time, whereas static loading does not consider the progression but focuses only on its final result, i.e., the steady state link volumes and conditions. In static loading, given the path flows and the set of links making up each path, calculating the resulting link flows is a matter of simple addition; the flow on any link can even be calculated without considering other links. In a dynamic model, given the same kinds of information, determining the flow on a link *at a particular time* requires knowing the time-varying traffic conditions on upstream links, and these conditions are themselves affected by the flows on those links.

The dynamic network loading problem can be formulated in a natural way as a fixed point problem: dynamic link flows are determined by dynamic link traversal times, and the congestion these flows create must in turn result in the same dynamic traversal times. In simulation-based models, loading is frequently accomplished simply by “moving” simulated vehicles through the network in one time step, and then updating traffic conditions for the next step; a small time step is generally used to minimize the approximation errors introduced by time discretization.

Researchers have proposed a variety of ways of solving mathematical versions of the problem; some of them involve MSA-type procedures.

5.1.3.4 Dynamic user equilibrium

The task of a DTA model is to ensure that the network conditions that were the basis for associating trips with paths coincide with the conditions actually encountered by trips. Corresponding to the two definitions of path travel time discussed above are two distinct notions of dynamic equilibrium, termed *instantaneous* and *experienced* dynamic user equilibrium, respectively. If path choice based on minimum experienced time were assumed, for example, the model would attempt to ensure that a path that was thought to provide the least experienced time before loading did in fact do so after loading. DTA models attempt to determine a dynamic equilibrium in the sense that, according to the path choice assumptions incorporated in the model, and the network conditions that result when tripmakers pursue those choices over the network, no trip has an incentive at any time to change from the path it is following to some other path.

The first rigorous formulation of the dynamic traffic assignment problem is due to (Merchant and Nemhauser 1978); since then, mathematical approaches to formulate and solve dynamic traffic equilibrium problems have been the subject of active research. The mathematical analysis of such problems is highly complex (much more so than for the static problem), but through such analysis the basic characteristics of the problem and the properties of its solutions can be elucidated.

Much current work in the area involves the development and use of simulation-based dynamic traffic models, which lack strict mathematical rigor but allow an arbitrarily detailed representation of vehicle dynamics and driver behavior. Simulation models are generally felt to have the potential to provide the degree of modeling realism appropriate for practical, operational use in applications such as real-time network management or information provision.

5.1.3.5 Fixed point approach to dynamic traffic assignment

The dynamic traffic assignment problem also can be expressed as a fixed point problem involving the composition in either order of a path choice and a dynamic network loading map. In this case the underlying variables are time-dependent. We will write $p\{t\}$ and $c\{t\}$ for the path choice probabilities and link conditions, respectively, at a particular time t, and simply write p and c for the entire set of path choice probabilities and link conditions at all times (or time steps) over the considered analysis time period. The dynamic network loading model $S: P \rightarrow C$ takes as input the set of path choice probabilities P at all times over the analysis period, and outputs the corresponding link conditions C at all times. The path choice model $D: C \rightarrow P$ takes as input the set of link conditions C at all times over the analysis period, and outputs the corresponding set of path choice probabilities P at all times.

With these conventions, the DTA problem can be written as either of two fixed point problems that are formally identical to those that were discussed above for the static problem: $c = S°D(c)$ or $p = D°S(p)$. Because of the identical formal structure and other commonalities in the characteristics of the two problems, similar high-level fixed point solution algorithms can be applied to them; for example, versions of the MSA are commonly applied to solve DTA problems. However, the lower level details of the solution algorithms, such as the way that the solution variables are stored and accessed, or the operation of the network loader, are clearly quite different for the static and dynamic problems.

5.2 Difficulties of modeling ATIS in conventional DTA models

5.2.1 TERMINOLOGY

Some discussions of ATIS distinguish between prescriptive content (e.g., a route recommendation), which is referred to as *guidance*, and descriptive content (e.g., data about traffic conditions), which is referred to as *information*. This fine distinction will not usually be germane to the discussion here; indeed, as was noted in the literature review, messages that combine both descriptive and prescriptive content ("30 minute delays ahead, take alternative route XYZ") generally achieve the highest compliance rates by drivers. We will refer to any data provided to drivers by an ATIS as a *message*, and generally use the terms *information* and *guidance* interchangeably, unless otherwise noted. A specific message is characterized by its content and format, as well as its reception area and (in dynamic models) its time and duration of dissemination.

Three types of guidance can be distinguished, based on the type of information used to generate the guidance messages. *Fixed* guidance[8] provides travel-related information about things that rarely change. Examples of fixed guidance include guidebook-type information (locations and features of different attractions such as restaurants or museums) and basic way-finding directions that are not tied to actual traffic conditions. In contrast to this, reactive and predictive guidance base their messages on real-time measurements of actual traffic conditions over the network.

With *reactive* guidance, the guidance messages are based more or less directly on the real-time measurements of prevailing (instantaneous) traffic conditions; for example, a message might provide information about current traffic conditions on some link, or recommend a path that minimizes travel times as currently measured on links. With *predictive* (or *anticipatory*)

[8] The term *static* guidance is also used, but will be avoided here to prevent confusion with static traffic assignment models, a completely unrelated concept.

guidance, on the other hand, the real-time traffic measurements are combined with other data and used to make short- to medium-term forecasts of (experienced) traffic conditions throughout the network. These forecasts are then the basis of the guidance messages disseminated to drivers. For example, a message might provide information about what the traffic conditions will be on some link at the time in the future that the driver will actually arrive there, or suggest a path that minimizes the experienced travel time to the destination.

5.2.2 EXAMPLE

It was mentioned above that conventional dynamic and static assignment models assume that drivers have complete information on network traffic conditions relevant to their decision-making prior to their departure from the origin. Of course, if this assumption were at all realistic, there would be little need for ATIS! An ATIS provides travel-related messages to drivers precisely because their usual information basis for trip decision-making is imperfect, and drivers who exclusively rely on such “background” information might easily make sub-optimal travel decisions. Do such messages place tripmakers in the full information situation assumed in conventional traffic prediction models? Can a conventional traffic model be used to make the required traffic forecasts and to generate the guidance messages?

Consider a traffic network with a short-range source of traffic guidance – a variable message sign, for example, or a low-power infrared or microwave transmitter for in-vehicle receivers – located somewhere on it. The guidance source provides to nearby vehicles summary messages, based on real-time traffic conditions, about expected traffic conditions in the future.

Drivers leaving their origin do not have real-time traffic information available to them, so they must base their path choice on imperfect background information from some other source. Consider two identical drivers leaving at the same time from the same origin, going to the same destination and with the same background information. Consistent with a random utility path choice model, they may nonetheless decide to take different paths. Suppose that the path of one of the drivers does not go by the guidance source, while that of the other driver passes near the guidance source in the middle of the trip. The former driver will presumably follow to the destination the path selected at the origin. The latter receives guidance en route and interprets the summary message in some way. As a result, she may decide to switch to a different path, possibly to a different destination, conceivably even to a different mode. The aggregate tripmaking changes that result from many such drivers’ responses to the guidance messages may affect subsequent traffic conditions downstream of the information source, and possibly throughout the network. As a result of these changes, the network conditions are different from what was initially expected, and the guidance messages prove to have been incorrect.

5.2.3 DISCUSSION OF EXAMPLE

This simple example highlights most of the issues that must be addressed in modeling ATIS in a traffic assignment model.

First, guidance is provided because drivers without guidance have imperfect knowledge of the network conditions that are relevant to their real-time tripmaking decisions. It is therefore necessary to represent the no-guidance background information basis, and to model drivers' decision-making processes in this situation.

ATIS attempts to supplement drivers' no-guidance information basis with guidance messages. However, for technological or other reasons, the quality of the guidance information might itself be less than perfect. For example, guidance might not be available to all network users because its reception might require special equipment. Even to vehicles equipped to receive it, guidance might not be ubiquitous (available everywhere on the network) because its reception range might be limited to a relatively short distance from specific dissemination infrastructure such as VMS or infrared beacons. Constraints on communications bandwidth and human information processing abilities might reduce the level of detail and precision of the information that can be conveyed in the guidance messages: highly detailed and precise messages are unlikely to be available in many systems. Computation and communication delays might leave drivers with out-of-date guidance. The guidance itself might be inaccurately computed or perhaps corrupted during transmission.

It is readily conceivable that, for a given network and travel demand pattern, two guidance systems, differing in one or more of the above aspects – for example, the location and range of the guidance transmitters, or the quality and quantity of the information provided – may have very different impacts on network traffic conditions. It follows that realistic guidance system modeling must be able to represent the specific characteristics of the system and the information that it provides to drivers. This point is emphasized by (Dehoux and Toint 1991).

Having represented the characteristics of guidance information, realistic modeling must also accurately capture the diversity of possible driver responses to the disseminated messages. Some drivers may rely heavily on guidance information, interpreting it more or less effectively in their decision-making processes; others may choose to do the opposite of what the guidance suggests in an attempt to "avoid the crowd"; yet others may ignore it completely and follow their habitual choices. Modeling driver response to guidance messages will almost inevitably be more complex than traditional driver behavior and path choice modeling, in which questions of information format, content, availability and accuracy do not arise.

An additional issue in driver modeling is the response to ATIS messages in an en route situation. A pre-trip choice (with or without guidance information) is a commitment without immediate antecedent, whereas an en route decision may entail a reluctance to revisit or to revise a path choice that was made earlier in the trip. For this reason, an en route decision may exhibit some form of hysteresis or threshold effect. Conventional path choice modeling rarely needs to consider such effects.

The possibility of en route path switches also leads to a difference in the functionality that network loaders must provide in conventional and guidance-based traffic models. Conventional network loaders propagate flows on complete paths from origin to destination and determine the resulting network conditions. Guidance modeling requires a network loader that can re-route flows at en route locations in accordance with given path probabilities there, and can determine the effect of such path switches on link flows and conditions on the downstream sub-path between the switching location and the destination. Note that pre-trip guidance affecting the path choice decision made at the origin does not pose any new problem for a network loader – it must propagate traffic along complete paths, just as it must in conventional traffic models.

Finally, when guidance involves information about future traffic conditions, then network guidance modeling must ensure that the guidance is *consistent* – in other words, that drivers' reactions to guidance messages based on assumptions about the future do not invalidate those assumptions. Because the guidance is based on future conditions, some kind of forecasting model that takes account of guidance messages will likely be used. Consistency is simply the requirement that the inputs and outputs of this model do not contradict each other. It is a generalization of traffic equilibrium. Whereas the equilibrium concept applies to conventional traffic models in which information is implicit, consistency applies to guidance-based or similar models, in which information and drivers' reactions to it are explicitly taken into account.

Suppose, for example, that guidance is generated using a dynamic traffic network model based on experienced (i.e., predicted) travel times. The model might indicate impending congestion in a particular corridor. It would seem reasonable to disseminate guidance messages to warn drivers there or perhaps suggest an alternative route. However, if these messages are tested using the guidance model, drivers' reactions to them could well cause the congestion to shift, leaving the original corridor relatively uncongested and perhaps resulting in worse overall travel conditions. This shows that the guidance messages were not consistent – within the model, the forecast traffic conditions that were the basis of the guidance messages did not materialize after drivers received the messages and reacted to them.

In practice, of course, a guidance system's forecasts will have to be updated periodically to take into account the latest data collected from network sensors and to correct any inaccuracies that may have crept into the forecasts due to random disturbances or major disruptions such as incidents. Many systems have adopted a rolling horizon approach to handle this ongoing need to revise and update earlier predictions. The issue here is different: if the prediction and guidance generation procedure does not incorporate some way of including traveler response to the guidance in the forecasts themselves, the forecasts and guidance will be inconsistent and systematically biased. No amount of updating by a rolling horizon or other approach will be able completely to correct for this error.

The issues associated with consistency are perhaps most clear in the case, as above, of dynamic models with predictive guidance. However, they arise even in static guidance models. Note that there is no meaningful distinction in a static model between experienced and instantaneous travel times (or between predictive and reactive guidance) since, by assumption, the steady-state conditions accurately reflect both current and future flows and conditions over the analysis time frame. Guidance messages both reflect and affect the steady state, and so the consistency issue arises even here.

5.2.4 CONCLUSIONS

In summary, adequate incorporation of traveler information effects in network-level forecasting requires a traffic model that can:

- predict what driver behavior will be in the absence of guidance;
- represent guidance messages: their content, format, reception area, availability constraints and (in dynamic models) time and duration of dissemination;
- predict the effects of guidance on driver behavior, in the form of pre-trip decisions to choose a path and en route decisions to switch from one path to another;
- predict the traffic flows and conditions that ensue as a result of travelers' responses to guidance, particularly taking into account en route path switches; and
- ensure guidance consistency.

Note that if an ATIS actually provided perfect information (conforming to the assumptions in a conventional traffic model), and if travelers reacted to this information as assumed by conventional models, then application of a conventional traffic network model to generate guidance would be justified. The conditions predicted by the conventional model could be disseminated to drivers, and would be accurate, consistent guidance. However, if the information provided by the ATIS is less than perfect (in the various ways discussed above), then ATIS does not create a full information situation, and basing guidance on the predictions of a conventional model would be incorrect. A different kind of traffic network model is called for.

(Watling and van Vuren 1993) provides an excellent discussion of many detailed issues that arise in the network-level modeling of ATIS. The following section proposes an overall modeling framework that accommodates the inter-relationships between demand, supply and travel information in a network context.

5.3 A traffic network model framework for ATIS modeling

It is possible to identify and discuss the appropriate structure of a traffic network model suitable for ATIS analyses even if, as was seen in the literature review, the current state of art does not yet permit a definitive choice to be made regarding the most accurate model of traveler response to guidance or the best representation of the detailed characteristics of guidance messages. This is similar, in many ways, to the presentation of conventional equilibrium models given above, where it was possible to make fairly definite statements about the overall model structure and equilibration requirements, without considering in detail the specifics of particular path choice or loading models.

The following paragraphs present the major elements that are sufficient to include ATIS modeling in a traffic network model. This is not necessarily the most general framework, and its description is intuitive rather than precise, but the important ideas and features are present.

5.3.1 MODELING ELEMENTS

In addition to the usual links, nodes and centroids that define traffic networks in the conventional modeling approach, general ATIS modeling also requires the identification of decision points, a subset of the nodes at which tripmakers might choose or switch paths based on messages received in their vicinity. All origin zone centroids are decision points; some or all of the other nodes in the network might be as well, depending on the availability of en route guidance. A broadcast highway advisory radio system accessible throughout a metropolitan area might be represented by decision points at every node, whereas systems with limited reception range would be represented by decision points at nodes in the reception area only.

Decision points decompose origin-destination paths into subpaths between the nodes and the destinations. At each decision node, flow chooses a path to follow from that point towards the destination; it follows that path unless it encounters another decision node, in which case it may switch subpaths.

A basic framework for analyzing ATIS in a traffic assignment context is defined by three variables and three maps that relate them. The variables are path splits, link conditions and messages. The maps are the network loading map, the guidance map and the driver response map. Some of these modeling constructs are similar to, but not the same as, the corresponding constructs that were discussed above in the context of conventional traffic equilibrium modeling.

5.3.2 FRAMEWORK VARIABLES

Path splits P are the probability that drivers at a decision point will follow the various available paths leading from that decision point to their destination. They are a generalization of the path choice probabilities used in the conventional traffic network model, the difference being that path splits are defined not just at origins, but instead at any decision point.

Guidance information M is disseminated in the form of discrete units called messages. The representation of a message involves its content and format, the location (decision point) where it is disseminated and, in dynamic models, the time and duration of its dissemination. Further distinction may be made between different classes of messages available to different classes of users (e.g., radio messages that require special equipment to receive and decode). It is assumed that vehicles on links immediately upstream of a decision node can receive messages disseminated there (if they are equipped to receive them.)

Link conditions C are identical to their definition in the conventional network model.

5.3.3 FRAMEWORK MAPS

The network loading map S determines the link conditions that result from the movement of the exogenous OD demands over the network in accordance with given path splits P. As discussed above, network loading maps for ATIS applications must be able to handle en route path switches, something that conventional loaders are not designed to do. At the time of this writing, there does not appear to be any rigorous analysis of network loaders of this type published in the technical literature. However, there is no particular difficulty in understanding, in algorithmic or software terms, how such a loader would operate; indeed, packages such as DYNASMART-X and DynaMIT incorporate dynamic loading software modules with re-routing capabilities.

Operations that a loader carries out in a conventional traffic model for traffic departing from the origin must be carried out in ATIS models for traffic leaving any decision point. Whether at an origin or an en route decision point, the loader needs to allocate outgoing traffic among the available paths or subpaths in accordance with the path splits, as well as propagate vehicles downstream from the decision points, do any necessary bookkeeping, and determine the travel conditions that result.

In static models, this can be accomplished by applying a recursive loading procedure that, at each decision point beginning with the origin, splits path flows and propagates the resulting subpath flows along links until another decision point is reached. At each decision point the procedure is recursively re-invoked. A recursion terminates when the destination is reached.

In dynamic models based on vehicle simulation, this can be accomplished by determining, for each vehicle about to leave a link, whether the link's end-node is a decision point; if so, the vehicle selects of the available downstream subpaths to the destination in accordance with the path splits at that node. For dynamic analytical models, the variety of network loading methods makes it difficult to generalize; however, some of these methods group flows into packets which are moved rather like vehicles in a simulation system, so the method proposed for simulation models would apply, with appropriate modifications, to these models as well.

The guidance map G determines the messages that will be disseminated in response to a given set of network conditions. It can be thought of as representing the message selection strategy applied by the traffic information center being modeled. Recall that, by definition, a message is location- (and, in dynamic models, time-) specific. Thus, the guidance map determines not just what messages to display, but where (and when, and for how long) to display them. Although the link condition predictions output by the loading map are complete (i.e., they cover all network locations and, in dynamic networks, all times), there is no requirement that the generated guidance messages convey guidance information or recommendations having a comparable degree of detail, precision or network coverage. A set of detailed condition predictions from the network loading map might be summarized in messages such as "expect congestion ahead for next 30 minutes" displayed at one or two locations; a complete minimum path calculation might be summarized as "turn left at next traffic signal", with further routing information provided at subsequent decision points. There is no corresponding map in conventional traffic models.

The driver response map D predicts the path splits that result from drivers' responses to a given set of guidance messages. The map is a generalization of the path choice component of conventional traffic assignment models. In conventional models, the path choice model relates path splits at trip origins to path attributes, which are in turn are directly derived from link conditions; under the full information assumption, these are assumed to be known to drivers. In guidance models, on the other hand, path splits at decision points (origins or otherwise) are related to the guidance messages that are available there, and these messages are indirectly derived from network conditions via the guidance map. The map encapsulates the effect of guidance messages on path splits. In reality, of course, drivers may base their route choice decisions on a wide variety of other factors, including their general knowledge of traffic conditions, their prior experience (if any) with the guidance system, etc. It is not intended to neglect these other influences; rather, it is assumed that they have been subsumed in the driver response map, leaving a direct relationship between path splits and guidance messages only.

It is worth emphasizing the generality of the framework, and the way in which its various components are interrelated. For example, we have frequently used travel time as an example of a condition variable, and travel time-based descriptive or prescriptive information as an example of guidance messages. Actually the choice of condition variable can be essentially arbitrary.[9] What is important is that, given path splits, the network loading map must be able to compute whatever particular condition variables have been chosen. Similarly, the format and content of the message variables is essentially arbitrary. What is important is that the guidance map must be able to generate the appropriate messages for any possible condition variable values that may be output by the loader. Finally, the guidance map must be able to predict the path splits that result from any set of messages that may be generated by the guidance system, but the way in which it does this can be arbitrary.

5.3.4 COMPOSITE MAP FORMULATIONS OF GUIDANCE CONSISTENCY

The above considerations lead naturally to the definition of composite maps that combine the network loading, guidance and driver response maps in different sequences. Each composite map takes input in the form of a value of one of the variables discussed above, and transforms it into a (possibly) different value of the same variable. In fact there are three such composite maps:

- a composite map $D \circ G \circ S: P \to P$ from the domain of path splits into itself, which starts with path splits, forecasts the corresponding network conditions, determines an appropriate set of guidance messages, which are disseminated to drivers and cause them to respond in some way, leading to a new set of path splits;

- a composite map $S \circ D \circ G: C \to C$ from the domain of link conditions into itself. The map begins with a set of link conditions and determines the messages which the ATIS disseminates about them; these are communicated to drivers, who respond and possibly change the path splits; the flows propagating over the network in accordance with these changed path splits then lead to a new set of conditions;

- a composite map $G \circ S \circ D: M \to M$ from the domain of guidance messages into itself. Here the map begins with a set of messages, predicts the resulting path splits, forecasts the network conditions that ensue from these, then determines a new set of messages appropriate for these conditions.

In operational terms, evaluating one of these composite maps corresponds to executing one iteration of an ATIS network forecasting model that invokes the component maps in the indicated order of composition. The input to the model is an assumption about the value of one of the modeling variables (path splits, conditions or messages); its output is a prediction of a

[9] Actually, in dynamic models travel time *must* be one of the variables output by the loader because of its role in establishing traffic dynamics. However, there is no requirement that the guidance map take account of travel time in generating messages, for example ("incident ahead, take alternate route").

possibly different value of the same variable. This can be written using a "functional" notation {i.e., function (input) = output} as:

model (assumptions) = predictions

Recall that guidance generated by a model is said to be consistent when the assumptions used as the basis for generating it prove to be verified, within the logic of the predictive model, after drivers receive the guidance and react to it. In terms of the composite maps, consistency means that a map's output predictions coincide with the input assumptions. Again, this can be written as:

model (assumptions) = predictions = assumptions

For the composite path split map, guidance is consistent if the forecast path splits coincide with the splits that were assumed at the start. For the composite network condition map, guidance is consistent if the initial network conditions used for the guidance determination coincide with those that are predicted to result after the guidance is disseminated. For the composite message map, guidance is consistent if the resulting messages coincide with the initially-assumed set of messages. Under mild conditions, solving any one of these problems is equivalent to solving any of the others.[10] There is not yet enough experience acquired with ATIS network models involving the different composite formulations to draw definite conclusions regarding their advantages and disadvantages, either theoretical or computational.

It can be seen that guidance consistency corresponds to a fixed point of a composite map that combines the relevant problem relationships. By solving one of the fixed point problems, a consistent value for the corresponding variable is determined, and from that value the solution values of the other variables can also be found. For example, if a fixed point $c^* = S \circ D \circ G\ (c^*)$ of the composite condition map is found, the resulting condition values account for the effects of the guidance messages on driver behavior, and the impacts of this behavior on network conditions. The consistent messages m^* can then be found by evaluating the guidance map using the fixed point conditions: $m^* = G(c^*)$. The driver responses (i.e. path splits) p^* to these messages can then be found via the driver response map $p^* = D(m^*)$.

Unlike conventional static and dynamic equilibrium problems, for which a variety of significantly different formulations are available, to the best of our knowledge the only approach currently available for general ATIS network modeling problems – involving a realistic representation of the guidance system and fully accounting for consistency – is via a fixed point formulation.

[10] Again, formulating a problem having a deterministic driver response map in terms of path splits may lead to a more complex situation because in this case path splits may not be uniquely defined at consistency. This problem does not occur if the composite condition or composite message maps are used.

A number of researchers have proposed ATIS modeling approaches similar in spirit to that described here. (Rilett and van Aerde 1991b) argued for the importance of providing routing information based on anticipated travel times. (Kaufman, Smith et al. 1991) was an early effort that treated guidance generation as a dynamic traffic assignment problem, but proposed a fixed point approach to formulate and solve it. Aspects of this approach to guidance via the DTA problem were pursued and analyzed more rigorously in (Kaufman, Smith et al. 1998). (Kaysi, Ben-Akiva et al. 1993) considered a more general notion of guidance, clearly defined the notion of guidance consistency, and evoked the possibility of analyzing it using fixed points, but did not pursue or formalize this idea. (Engelson 1997) also recognized the importance of predictive consistency, and its fixed point interpretation, in DTA-based guidance generation. (Bovy and van der Zijpp 1999) considered a general guidance system and analyzed it with a particular fixed point formulation. The framework proposed here is a generalization of these prior approaches. Its elaboration in a dynamic network context is presented in (Bottom 2000).

5.3.5 RELATIONSHIP TO EQUILIBRIUM MODELS

A conventional full information equilibrium model assumes that the path choice decision is made at the origin and is not reconsidered en route. Drivers are assumed to have accurate perceptions of the attributes of alternative paths and to choose a path that maximizes their perceived utility (although this choice may nonetheless seem random to a modeler who is not fully aware of the driver's decision situation). The loader propagates traffic along these paths from origin to destination, and determines the corresponding traffic conditions.

In terms of the guidance modeling framework proposed here, the only decision points in equilibrium models are at the origin. The network loader does not need to handle en route path switch situations. The guidance map (transforming network conditions into messages) is a kind of identity map I: the messages perfectly convey the exact network conditions. The driver response map reacts to these fully-informative messages in the same way that drivers are assumed to react to full information on conditions in the conventional model.

In this situation the composite condition map $S \circ D \circ I : C \to C$ and the composite message map $I \circ S \circ D : M \to M$ become equivalent. Only two distinct maps remain: the composite path split map $D(\circ I) \circ S : P \to P$, which is the same as $D \circ S : P \to P$; and the composite condition map $S \circ D(\circ I) : C \to C$, which is the same as $S \circ D : C \to C$. But these are the same as the two composite maps that were considered above in the discussion of fixed point formulations of conventional models. Consistent guidance, in this context, involves a fixed point of one of these two composite maps, which, as was seen above, is equilibrium.

To summarize, the conventional full information equilibrium model can be viewed as a special case of a guidance model in which the guidance information is perfect.

5.3.6 SOLVING ATIS NETWORK MODELS

As has just been seen, solving an ATIS network problem to obtain consistent guidance and its impacts can be accomplished by finding a fixed point of the composite map that is chosen to represent the problem. The basic approach for computing such a fixed point is no different in principle from that used to compute fixed points of conventional equilibrium problems. The general ideas are sketched out, from the viewpoint of developing software to address the problem, in the following paragraphs.

Fundamental choices about the type of model (i.e. static, simulation-based dynamic, analytical dynamic) have to be made at the beginning and, conditional on the choice, capabilities provided to support the basic operations (network creation and manipulation; data input, storage, access and output; time functions in dynamic models; etc.) that the model type requires. Many of these functions are fairly generic within each type of model. It is possible that portions of code prepared for conventional equilibrium models could be reused for these purposes (this would depend, of course, on implementation details).

Consensus has not yet been reached on some fairly basic issues in ATIS network modeling, such as the most appropriate representation of guidance messages or the form and specification of the driver response or message generation maps. Consequently, it may be most straightforward and efficient to tailor a software implementation to the particular problem at hand, rather than attempt to provide capabilities to handle these issues in a very general way.

Clearly, software to implement each of the component maps (i.e., network loader, driver response and guidance message generation) will need to be prepared; each map should be implemented as a distinct function (in the programming sense), accepting and returning the appropriate types of argument. The composite map constructed from these three components should be as efficient as possible, since its evaluation will be the bottleneck in the solution algorithm.

The MSA can be applied to compute the fixed point of the composite map chosen for the guidance problem, just as it is for conventional equilibrium problems. Of course, the same caveats apply to the two problems. In particular, no general result guarantees that the MSA applied to this problem will converge to a fixed point. Despite this, the observed performance of the algorithm is frequently satisfactory and, in problems without significant noise, the correctness of the computed solution can easily be checked by verifying the fixed point property.

As an example, the listing below shows the MSA logic applied to the composite link condition formulation of an ATIS network model. The algorithm evaluates the link condition composite map $d_k = S \circ D \circ G\ (c_k)$ in steps 1—3. This evaluation would be accomplished in the software by calling in succession the functions implementing the guidance map, the driver response map and the network loader. The close structural resemblance of this algorithm to the one presented above for the composite link condition equilibrium formulation is evident.

0:	c_0 = free-flow link costs; k = 0	*initialize*
1:	$m_k = G (c_k)$	*get messages based on current link costs*
2	$p_k = D (m_k)$	*get path splits based on messages*
3:	$d_k = S (p_k)$	*get auxiliary link costs based on path splits*
4:	if convergence is achieved, stop	*if converged, c_k is the solution; else continue*
5:	$k = k+1$	*bump iteration counter*
6:	$c_k = c_{k-1} + (1/k) * (d_{k-1} - c_{k-1})$	*update link costs*
7:	go to step 1	*iterate*

The often slow convergence of the MSA was mentioned above. This can be a particular problem in dynamic models because of the number of elements (dimension of problem variable multiplied by number of time steps) that must be adjusted to reach a fixed point, and because dynamic network loading is typically a computationally intensive procedure. The problem is even more acute in dynamic ATIS network models when they are intended to generate guidance in real time.

A number of methods to improve the convergence rate of the MSA (and similar algorithms) have been proposed over the past decade. While some of these are heuristics, an algorithm by Polyak (1990) (see also Polyak and Juditsky 1992)) is rigorously applicable whenever the MSA is, and can be shown to have optimal convergence properties in a certain sense. Polyak's algorithm is easy to implement and represents a very minor additional computational effort beyond the MSA algorithm. It also seems to improve the performance of the MSA even in applications where the MSA is not provably convergent. Methods such as Polyak's hold considerable promise for improving the solution speed of ATIS network models in both planning and real-time applications.

(Bottom 2000) describes software that implements fixed point approaches for dynamic network traffic modeling with ATIS, and tests the MSA and Polyak algorithms as solution methods. It was found that the Polyak algorithm could outperform the MSA (in terms of the number of iterations required to attain a certain degree of convergence) by factors of four or more. Its further application to fixed point formulations of traffic network problems would appear to be very promising.

Document reviews

Aarts, H., Verplanken, B., and van Knippenberg, A. (1997). "Habit and Information Use in Travel Mode Choices." *Acta Psychologica*, 96, 1-14.

This study investigates the effects of habit on information processing during decisions about travel mode use. The purpose of this study is to test the hypothesis that strength of habit is negatively related to the elaborateness of information processing in decisions about travel mode use. The study focused on the decision to use a bicycle for short distance trips. It is expected that individuals who have developed a strong bicycle choice habit apply less elaborate information processing strategies compared to those who have not developed such a habit.

Habit can be considered as a person related, stable factor, which affects the decision-making process on a recurrent basis. That is, once habits toward a particular behavior are formed, individuals need only engage in minimal information processing each time they encounter comparable situations that call for the same behavior. However, the depth of the decision-making process may also be contingent on situational factors, for example, when the decision has significant consequences for the individual. For that reason, it is conceivable that even people with strong habits may occasionally be motivated to base their decisions on relatively more extensive information processing. In the present study an attempt is made to experimentally enhance the depth of information processing that underlies travel mode choices by introducing situation-specific demands.

Subjects of the experiments were 82 students of the University of Nijmegen. Because their task was to evaluate the usefulness of the bicycle in different travel situations, only people who owned a bicycle were recruited as subjects. Subjects were presented with nine generally described trips (e.g., going to a supermarket to shop, visiting friends), all of which had four available modal alternatives (walking, bicycle, train and bus). In each case, the choice was made in the context of a particular trip situation that was described to the subject. The subject was then required to state, as quickly as possible, the mode choice that came to mind. Each situation was characterized by four attributes (weather conditions, weight of luggage, departure time and distance to the destination), each of which had two possible values. The values were combined across the attributes according to a fully balanced design, resulting in the construction of 16 possible travel situations. The order of presentation of attributes was varied in different experiments. Subjects also indicated their attitude towards using the bicycle in each travel situation on a 10 point scale ranging from 'unfavorable" to "favorable".

For the 16 trip situations, subjects' attitudes towards bicycle use were regressed on the attribute values characterizing the situation. (Since the attributes are uncorrelated in the experimental design, multiple linear regression analysis yields efficient and unbiased estimates.) The resulting coefficients represent the direct contribution of each attribute in subjects' attitudes across the 16 trips. Standard deviations of the coefficients were also calculated; these can be used, for example, to test whether subjects allocate equal importance to the different attributes.

The results of the study indicate that habit affects the elaborateness of decision-making concerning travel mode use. In comparison to weak habit students, strong habit students used fewer attributes about the circumstances under which the trip had to be made. In addition, strong habit individuals were more selective than weak habit individuals were in using information on the attributes of choice options. These results suggest that habitual travel mode choices are based on a small subset of trip related cues necessary to make these choices. In addition to the effects of habit, subjects devoted more effort to decision making when they were held accountable: subjects who had to explain their judgments used more attributes and seemed to process the information more consistently than those who were not accountable.

Abdel-Aty, M. A. (2001). "Using ordered probit modeling to study the effect of ATIS on transit ridership." *Transportation Research C*, 9, 265-277.

This study is an attempt to aid in the development of effective transit information systems and to assess their potential usefulness. The ordered probit modeling approach was used to estimate the commuters' likelihood of using transit given that different types of information are provided. The objectives of the study are:

- to determine which types of information are more important to users;
- to identify the significant transit attributes;
- to explore the commute and socio-economic factors that affect the likelihood of using transit given information was provided; and
- to assess commuters receptiveness of such an information system.

The study is based on data collected in a telephone interview from 1000 morning commuters in two areas in Northern California (Sacramento and San Jose). The survey was designed with two main branches. The first is for transit users, and the second is for non-transit users. The reason is that one of the main objectives of the study is to determine the likelihood of using transit, given the availability of transit information, for commuters who are not currently using transit. For commuters who are using transit, the level of satisfaction with transit information is identified. A transit user was defined as an individual who used transit at least once in the last 14 days. Non-transit users encompass individuals who drove alone, carpooled or used other methods of travel to work, but not transit. This group was asked to rate their likelihood of using transit at least one day per week given that transit information is available at their homes. Also non-transit users were asked if they might consider transit if more information were available, or if they absolutely need their car. A stated preference (SP) choice set was presented to those respondents who indicated that they might consider transit.

Respondents were asked to rank the top three most important information items that may need to consider transit as an alternative commute mode. Using 1-10 scale with 1 being extremely unlikely and 10 being extremely likely, they were asked about their likelihood of using transit as a commute method at least one day. The ordered probit model was used as the dependent variable takes more then two values, and the values have a natural ordering. It would be inappropriate to use the multinomial logit because this model does not account for the ordering of the dependent variable. Further, a regression model would not be appropriate because it assumes differences between categories of the dependent variable to be equal, whereas, the data are only ordinal. The ordered probit model provides the thresholds which would indicate the levels of inclination toward using transit, so there are no arbitrary assumptions about the magnitudes of differences between categories of the dependent variable.

The levels of each transit attribute were entered into the model as dummy variables. These attributes are assumed to be provided by the information system according to the SP design. This effort would enable the identification of whether the respondents use the information provided to use transit, and what are the significant attributes that are considered important by the respondents. In the estimation process of the model, two sets of variables were entered. The first is the variables that represent the commute attributes and the socio-economic characteristics, and the second is the dummy variables that represent the levels of each transit attribute provided by the information system.

Travel time by transit and the log of the commute distance affect the likelihood of choosing transit as the commute mode. Commuters who currently carpool are more likely to use transit. Among the socio-economic characteristics, age, income, and education level, seem to be influencing the choice of transit. In general, the results indicated the potential of transit information for certain groups of the population. About 38% of non-transit users indicated that they might consider transit use if appropriate transit information was available to them.

Abkowitz, M. D. (1981). "An Analysis of the Commuter Departure Time Decision." *Transportation*, 10, 283-297.

This paper deals with the development and empirical estimation of a disaggregate model of commuter departure time choice during the morning peak period. This research was directed at extending the study of commuter departure time decisions to expand the market to include transit commuters, including consideration of a wider range of socio-demographic characteristics, accounting properly for the travel time uncertainty in departure time choices, and improving the definition of arrival measures.

Data collected in 1972 in the San Francisco Bay Area for the Urban Travel Demand Forecasting Project (UTDFP) was used for this research. A subset of this data set comprising 425 respondents was selected. For each individual in the sample, information was available concerning travel alternatives, actual choices, perceptions, socio-economic characteristics, official work start time, actual departure time, work arrival time and work schedule flexibility.

Departure time choice was modeled conditional on mode choice, based on a priori behavioral beliefs about the sequence of decisions. A logit model formulation was used. The departure time period of study ranged from an expected arrival of 42.5 minutes earlier than the official work start time, to an expected arrival 17.5 minutes later than the official work start time. Twelve departure time alternatives were defined for the departure time model. Each alternative represented a five-minute departure time interval, and the data input for each alternative represented a discrete approximation of departure attributes for the continuous interval. It was assumed that transit service frequency was sufficiently high during the peak period that the full set of alternative choices was available to transit users.

A two-stage approach was used to select the most appropriate departure time model. The first stage consisted of selecting independent variables. Variables were introduced one at a time into the departure time specification. With the addition of each new variable, a logit model was re-estimated and the variable coefficients were examined for statistical significance, proper signs etc. The variables considered for inclusion in the departure time model in the first stage consisted of work arrival time flexibility, occupational characteristics, income, actual mode chosen, age, sex, location of residence and workplace, travel time and expected loss. The travel time expected loss variable was included to represent travel time uncertainty and relate it to the importance of on-time arrival at work. Separate expected early arrival loss and expected late arrival loss terms were used. In the second stage, the variables in the final stage 1 model were individually tested in alternative-specific specifications. This was done to identify additional explanatory effects in the departure time model.

The estimation results showed that-

- the availability of a flexible work schedule is important for people planning to arrive exactly on time and extremely important for those planning a late work arrival;

- auto travelers are more likely to plan on arriving at work exactly on time, while bus travelers are not likely to depart so as to arrive extremely early for work;

- individuals employed in a professional, technical, management or administration capacity typically avoid early arrival at work; and

- older workers and low-income workers are more inclined to arrive at work earlier than the official work start time.

A validation test was also conducted on sub-samples of the sample used for model estimation to determine whether the selected model was properly specified. Finally, a hypothetical example was conducted to show how a planner may use the departure time model for policy analysis.

Abu-Eisheh, S. A., and Mannering, F. L. (1987). "Discrete/Continuous Analysis of Commuters' Route and Departure Time Choices." *Transportation Research Record*, 1138, 27-34.

This paper develops and empirically estimates a route and departure time model for peak period travel. The departure time model developed in this study treats departure time as a continuous variable and thereby avoids any a priori restrictions (due to discretization of departure times) on the modeling approach.

The data set used for this study came from a 1986 survey of morning commuters in the State College, Pennsylvania metropolitan area. The survey was designed as a trip log and was a mail-back questionnaire survey. The number of usable observations was 151. Only one origin-destination pair was used. Three distinct and diverse routes connect the selected origin-destination pair. In addition to the commuter survey, extensive traffic-related data were collected for each of the routes connecting the OD pair.

A standard multinomial logit specification was first used to model route choice. The utility of a particular route is a function of the expected travel time on the route and a vector of route specific characteristics (e.g. number of traffic signals, queue lengths etc.). Expected travel time was as predicted by the Bureau of Public Roads' (BPR) equation. The use of expected travel time avoids endogeneity problems that would be encountered if actual travel times were used. The problem would arise because travel time and route choice decisions are interrelated and a correlation between travel time and the disturbance term would exist.

Departure time is modeled as a continuous variable and is a function of the work start time, travel time, work access time and delay cushion (defined as the time difference between work start time and arrival time). The work start work arrival times are assumed to be exogenous to the route and departure time choice process. Route travel time is modeled as a function of route specific characteristics, commuter socio-economic characteristics and commuter vehicle characteristics. However, since route travel time and route choice are interrelated, there is a selectivity bias. The expected value method is used to correct this problem: every route specific variable included in the travel time equation is replaced by its expected value. Route delay cushion is also modeled as a function of route specific characteristics, commuter socio-economic characteristics and commuter preferences for early or late arrival. The delay cushion model is also corrected for the possible selectivity bias. The travel time and delay cushion models are estimated by ordinary least squares.

The route/departure time choice modeling system could be used for user equilibrium traffic assignment. It also offers the potential to evaluate the traffic-related impacts of a wide range of policy options. Impacts of shifts in population demographics can also be assessed.

Adler, J. L., and Blue, V. J. (1998). "Toward the design of intelligent traveler information systems." *Transportation Research C*, 6, 157-172.

The authors of this paper distinguish between "advanced" and "intelligent" traveler information systems. The former represent the current state of the art or slightly beyond, characterized by:

- an interactive user interface, allowing limited two-way interaction with the ATIS, and presenting guidance messages in a visual or auditory format;
- vehicle location and intelligent mapping capabilities, based on GPS tracking;
- individualized path search based on driver-selected choice criteria;
- yellow pages for information about the activity system;
- multi-modal and multi-purpose information, covering both highway and transit systems, and assisting mode, departure time and route choice decisions; and
- dynamic route guidance based on real-time information on prevailing or predicted traffic conditions.

While these capabilities represent a considerable advance over those provided by first generation ATIS implementations (for example, variable message signs or highway advisory radios), the authors argue that they still fall short of what consumers generally expect from service providers – a more personalized service that, over time, becomes familiar with and learns to anticipate the needs and preferences of the customer. Through incorporation of artificial intelligence, natural language processing, machine learning, approximate reasoning, fuzzy logic and other cutting-edge technologies, the authors suggest that the next generation of intelligent traveler information systems (ITIS) should include capabilities to:

- recognize and retrieve information about drivers, without requiring them to input rarely-changing information each time they use the information system;
- learn about drivers either implicitly by observing their travel decisions, or explicitly by asking drivers to rate their perception of travel experiences. Eventually drivers' different behaviors and preferences on different kinds of trips (e.g., commute, shopping, recreational) would be distinguished and learned. The system would also track changes over time in drivers' behavior as their characteristics evolve, for example as they change as a result of more extensive experience of the network and guidance system, or;

- communicate with the driver in a relatively free-format interaction, including verbally using natural language. Ultimately the in-vehicle communicator would be able to correctly infer a driver's meaning from imprecise or incomplete statements;

- interface automatically with different real-time information sources in order to develop an information package or travel itinerary tailored to the tripmaker's particular preferences for specific types of trip; and

- minimize potential safety problems by selectively screening and aggregating the messages provided to drivers in order to prevent "information overload" while driving.

The authors claim that intelligent traveler information systems providing such capabilities would greatly enhance the viability and marketability of route guidance systems. The system they envision would effectively respond to drivers' path selection needs, and would adapt to changes in drivers' spatial knowledge, travel preference and general attitudes over time. Ultimately, today's traveler information systems would become machine intelligent travel decision assistants.

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Adler, J. L., McNally, M. G., and Recker, W. W. (1993). "Interactive Simulation for Modeling Dynamic Driver Behavior in Response to ATIS." Proceedings of the ASCE 5th International Conference on Computing in Civil and Building Engineering, ASCE, 591-598.

Adler, J. L., Recker, W. W., and McNally, M. G. "In-Laboratory Experiments to Analyze Enroute Driver Behavior under ATIS." *Transportation Research Board 72nd Annual Meeting*.

These articles describe the conflict theory approach to understanding en route driver behavior in response to information, as well as the FASTCARS (Freeway and Arterial Street Traffic Conflict Arousal and Resolution Simulator) PC-based travel choice simulator. (Adler, McNally et al. 1993) and (Adler, Recker et al. 1993a) particularly focus on presenting conflict theory and the design and features of the FASTCARS simulator.

Conflict theory postulates that human response to changes in the external environment is precipitated by stages of conflict arousal, motivation and response. Conflict arousal results from unexpected changes in the environment that conflict with a person's prior experiences and expectations. This causes a tension that motivates response and action through periods of frustration and dissatisfaction. The response will be conditioned by (1) the amount of arousal, (2) the motivation of the decision maker, (3) problem-specific factors and (4) associations among the cognitive elements. An individual's conflict tolerance threshold is a primary factor in predicting his or her response to conflict arousal; these thresholds differ from one individual to another based on idiosyncratic factors as well as prior experience. Response to the conflict leads to a resolution, which may take one of two general forms: innovation and adaptation. Innovation resolves conflict by adopting new behavior and generally occurs when both the arousal and the motivation are high; adaptation resolves it by restructuring objectives and expectations so that the tolerance threshold is increased, and is characteristic of low motivation.

In the context of en route driver route choice behavior, the theory implies that changes from an initially selected route must result from increased conflict arousal and motivation. Drivers encountering traffic conditions very similar to what they expected when originally choosing their routes would probably not change their prior decision. However, significant differences between expectations and actual driving experience could lead to increasing frustration, anxiety and tension and provoke a behavioral change.

The authors elaborate these ideas into a more detailed model of driver behavior, consisting of pre-trip planning, en route assessment and adjustment, and post-trip evaluation phases. The en route phase has four components: (1) initial travel strategies (from the pre-trip planning phase); (2) conflict arousal and motivation; (3) information acquisition and processing; and (4) travel adjustment. During pre-trip planning, a driver establishes a set of (possibly conflicting) goals to be achieved. Each goal is given a preference weight that reflects the importance of attaining it. Drivers select an initial path in accordance with these goals and weights (the authors define utility as a linear combination of the expected goal attainment level). If traffic conditions deteriorate, conflict arousal may lead to an eventual modification of the initial decision. Drivers perceive traffic conditions and locate alternative paths through the acquisition and processing of information resulting both from the driving experience itself and from external sources such as radio or variable message signs. Based on this information, drivers decide on their response to the conflict: do nothing, revise their goals, or switch to another route.

FASTCARS is a PC-based travel choice simulator developed for in-laboratory experimentation intended to gather data for estimating en route driver behavior models under conditions of real-time information. The simulator design was inspired by the conflict theory described above. It provides an environment that replicates spatial and temporal situations that produce conflict and motivation during travel, and allows researchers to vary a number of situational aspects in order to study travel decision making, including goal specification, route choice, diversion and information search. In the simulator, conflict can be initiated in two forms: through a driver's direct perception of worsening travel conditions, or by acquiring real-time information about such conditions.

The simulator accommodates different network configurations and system parameters through files prepared by the operator. Typical traffic conditions (speeds and incident probabilities) are input to the simulation, not computed endogenously. A display screen represents surrounding traffic conditions in a schematic form, together with basic data such as clock time and vehicle speed. "Drivers" indicate lane changes and turning movements through keyboard commands; the vehicle speed is determined as a function of link and lane.

Experimental subjects are given a departure time, destination and desired arrival time. They begin by choosing their preferred weights (totaling 100) for five goals: minimize schedule delay, minimize travel time, minimize number of stops, minimize distance and minimize number of decision points, and their "score" is determined based on their success in reaching each of these (measured on a scale of 0 to 100). Subjects may change their weights during a simulation, but each such goal revision is penalized by a factor that increases with closeness to the destination. The degree of attainment of each goal is also displayed on the computer screen at all times. Users attempt to maximize their total (weighted) score.

FASTCARS presents drivers with information from two sources: basic road signs, and ATIS, including variable message signs, highway advisory radio, and in-vehicle devices. VMS messages typically refer to traffic conditions or route recommendations, based on conditions downstream of the VMS location, and are made available when a VMS location is passed. HAR provides more detailed spoken (voice synthesized) information on conditions, and has to be explicitly accessed by the user, with a one-time score penalty. In-vehicle devices compute and display messages related to the shortest time path to the destination; there is a one-time score penalty for “turning on” the device, as well as a per minute penalty for continued use. The simulator records basic information about the subject, together with all decisions (driving, information acquisition, goal revision) made during the experiment and the simulation state information at the time of each such decision.

(Adler, Recker et al. 1993b) presents results from an analysis of experimental data collected using FASTCARS. A hypothetical road network, consisting of a beltway with freeways and arterials, was used for this purpose. Drivers’ network familiarity was represented by preparing three increasingly detailed sets of maps, denoted Novice, Intermediate and Expert. The novice maps show the trip destination and a few freeways, together with freeway distances. Intermediate maps cover the entire freeway system together with distances and speed distributions. Expert maps cover the entire network and provide information on freeway distances and speeds, probability of incident occurrence, and speed distributions on arterials. Subjects were initially assigned randomly to a familiarity level, then advanced to more detailed levels after completing four experimental runs at a given level. All experiments involved identical origin, destination, departure time and desired arrival time.

Data generated in these experiments were analyzed in a number of ways. Descriptive statistics and cross-tabulations showed, for example, that expert drivers were better able to achieve their trip goals and were less likely to consult the traffic information sources. However, in all cases higher levels of congestion produced higher frequency of access to information sources, and particularly to HAR. Drivers observing a VMS message indicative of traffic congestion had a high probability of subsequently consulting HAR or the in-vehicle devices, indicating that VMS can trigger the acquisition of more detailed additional traffic information.

Analysis of diversion behavior using a binary logit model showed that diversion probability is positively affected by VMS messages warning of congestion and by knowledge of alternative paths; and is negatively affected by average link speeds (higher speeds suggest a lack of congestion), by familiarity with the current route (drivers more familiar with their current route are less likely to divert), and when the potential diversion route is an arterial (rather than a freeway, indicating a “freeway bias”).

The authors also analyzed secondary diversion behavior (i.e., subsequent to an initial diversion) to determine if it was affected by different factors. It was found that the more a driver diverts, the more likely he or she was to divert again. This may be due to a change in diversion thresholds; however it was also found that, after a first diversion, a decrease in travel speed was less likely to provoke a diversion response.

Akamatsu, M., Yoshioka, M., Imacho, N., Daimon, T., and Kawashima, H. (1997). "Analysis of Driving a Car With a Navigation System in an Urban Area." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 85-95.

Graham, R., and Mitchell, V. A. (1997). "An Evaluation of the Ability of Drivers to Assimilate and Retain In-Vehicle Traffic Messages." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 185-201.

In the study by Akamatsu, Yoshioka, Imacho, Diamon and Kawshima, field experiments were conducted to explore driver behavior and the processing of information when navigation systems are used in real urban areas. Sufficient information by which to infer cognitive processes can not be obtained by simply observing a driver's behavior. So, a method based on subjective observation called the "thinking aloud" or "verbal protocol" method can be used to gather additional data in order to better understand the cognitive process. With the "thinking aloud" method all thoughts are vocalized, and the comments are recorded while the subject performs the tasks. Driver behavior while using a navigation system in the central area of Tokyo was recorded by means of small video cameras, and the landmark information used by drivers was analyzed using the "thinking aloud" method. In the analysis, verbalized words were categorized into several types of landmark information.

Eight different navigation systems were used and the results were analyzed together in order to avoid focusing on the characteristics of one particular system. The systems used in the experiment did not provide a route guidance function. Consequently, the drivers determined the routes by themselves using either a digital or a paper map and followed the chosen route on the digital map.

The number of glances per minute at the navigation system display was used as a measure of the frequency of use of the navigation system. The glancing frequency was found to vary along the route. Both the familiar and unfamiliar driver groups increased their glances at the display as they approached an intersection at which they intended to turn and decreased their glances after completing the turn. This observation suggests that it is important to design the interface and the digital map of the navigation system to enable the driver to easily identify the intersection that is seen through the windshield.

The recording of the drivers' comments indicated that the subjects used landmarks and other information along the route to identify their location. Consequently, when designing the display and the map database, it is necessary to know which landmarks are likely to be used as reference points.

Comparisons of the frequency of word use showed several differences between the familiar and unfamiliar driver groups. The results also indicated that both the navigation system's interface and the road traffic infrastructure should be designed to facilitate navigation by unfamiliar drivers.

Graham and Mitchell carried out a similar study. Giving drivers advance warning of an event can affect route choice and safety related factors such as driving speed. However, the success of such systems depends largely on the ability of drivers to assimilate, retain and act on the information received. These processes rely on the application of ergonomics to the design of the system's man-machine interface (MMI). This paper describes experiments evaluating various MMI aspects of a prototype in-vehicle system, and then make recommendations accordingly.

The task of using a visually based in-vehicle information display can be broken down into a number of stages of information processing. Messages must first be detected, which involves the initial stimulation of vision, and recognized as familiar before being read and interpreted. The efficiency of this initial assimilation process may be affected by the layout, legibility and complexity of the display. Some decision must then be made as to which elements of information are considered relevant. Finally, the relevant information is committed to memory until it must be acted on. The ability of drivers to recall traffic information depends on a number of factors including the display complexity, the modality of message presentation, the length of messages, the presence of other traffic and subject variables such as age and educational levels.

A road based experiment was carried out to examine both the assimilation process and the retention of information over time. Measures of recall performance and eye glance behavior were used to assess three factors associated with the design of driver information systems: the length of messages, the timing of messages, and driver age. The study compared the performance of two age groups of drivers using the system. Recommendations were made concerning the amount of information that should be displayed on the screen, the timing of messages in relation to events, and the presentation of message screens.

The study was conducted in winter on the main arterial freeway in the UK. Both traffic and weather conditions throughout the study were demanding, providing a rigorous but realistic test environment. Each subject required two sessions to complete the experiment. The first was concerned with familiarizing the subject with the car, screen and experimental procedure. The second session included the main experiment, followed by a brief post-drive questionnaire.

The study points not only to the way drivers assimilate and recall the information displayed on the screen, but also to a number of differences in the way younger and older drivers are able to deal with this information. The ability of drivers to recall messages was affected by the length and type of message, and the length of the retention period. Older drivers required longer glances to read the information and experienced retention problems for the most complex messages.

Al-Deek, H., Martello, M., May, A. D., and Sanders, W. (1989). "Potential Benefits of In-Vehicle Information Systems in a Real Life Freeway Corridor under Recurring and Incident-Induced Congestion." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 288-291.

This paper is a product of a PATH research study on the potential benefits of in-vehicle ATIS providing real-time traffic information.

The study simulated a portion of the SMART corridor in Los Angeles, California, including the Santa Monica freeway and three parallel surface streets, using the well known FREQ8PC and TRANSYT-7F simulation models. Simulations were done under recurring and non-recurring (incident) congestion conditions.

Link travel times obtained from these simulations were used to compute OD path times via the shortest or any other path. The shortest path was assumed to be the one that would be followed by travelers with perfect information; other paths considered were freeway-biased and arterial-biased. The arterial-biased route was chosen as an arterial parallel to the freeway. The freeway-biased route was designed to reflect the behavior of the majority of corridor users. The survey was conducted to identify typical and diversion routes used by actual commuters in the corridor.

Comparisons between the shortest path travel time and times on the other paths were made for four origins and three destinations, also selected based on the survey. The difference between the freeway-biased and minimum-cost routes represents the time-savings that might be available to a driver who has perfect information about travel times in the rest of the corridor.

The results indicated that under the recurring, non-incident congestion scenario, the travel time savings from utilizing the shortest path were generally negligible (less than 3 minutes for a 20-25 minute trip) compared to the travel time on other paths (usually the freeway-biased path). Under the non-recurring, incident congestion scenario (where the incident was on the freeway), travel time savings from choosing the shortest path were found to be significant (greater than 3 minutes) during certain times in the analysis time frame. The greatest travel time savings accrued during the time slices immediately following the incident occurrence, with a maximum savings of 10 minutes for a 30 minute trip. The results of this study are specific to the corridor under investigation.

Al-Deek, H., and Kanafani, A. (1991). "Incident Management with Advanced Traveler Information Systems." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 563-576.

This paper deals with an important application of ATIS technology: the management of incidents. ATIS is likely to be highly useful under conditions of non-recurring congestion, as may be caused by incidents. Under these conditions the lack of information about the severity and duration of an incident and its location vis-à-vis the rest of the network would leave the traveler insufficiently informed to make appropriate route choice decisions. Furthermore, by providing information to travelers before they approach an incident location, ATIS may further reduce the incident-produced congestion by altering trip patterns. This study applies deterministic queuing methods to analyze incident impacts in an idealized traffic corridor, in order to identify conditions under which route guidance information is useful and to estimate its benefits in incident conditions.

A deterministic queuing model of a simple corridor is used to simulate the occurrence of incidents of various locations, durations and severity. The model was used to analyze the benefits from ATIS and to study the sensitivity of these benefits with respect to some parameters; most important among them is the percentage of vehicles equipped with ATIS receivers. The queuing model is applied to a road network with two parallel bottlenecks under an off-peak incident scenario. Different cases of queue evolution that can result when a user optimal strategy is implemented are described. The benefits to guided/unguided traffic and to the system are analyzed.

The results showed that once equilibrium is reached between alternate routes, the rate of diversion from one to the other has to be decreased to maintain it. The decreased rate is function of the capacities of the two routes. The implication is that during equilibrium some equipped travelers will be diverted to an alternate route while others will be asked to stay on the route where the incident has occurred. As long as the fraction of vehicles equipped with ATIS is below a critical value, then all equipped travelers can be diverted and all diverted travelers can still gain the maximum possible savings. In addition, diversion of all equipped vehicles will not increase travel times of any equipped vehicles that may be using the alternate routes when diversion occurs in this case. Since system benefits are also maximized at the critical fraction of equipped vehicles, it is not recommended to divert more than this number to the alternate route in all circumstances. This is reasonable as long as the market penetration of ATIS is below the critical value.

The critical fraction of equipped vehicles depends on two corridor parameters, the capacity of the alternate route and the travel demand in the corridor. In a real life corridor, feasible alternate routes should be identified. The capacity that is used in calculating this critical function should be the total unused or excess capacity of all the feasible alternate routes.

Al-Deek, H., and Kanafani, A. (1993). "Modeling the Benefits of Advanced Traveler Information Systems in Corridors with Incidents." *Transportation Research C*, 1(4), 303-324.

This paper is concerned with an important application of ATIS technology: the management of incidents. Using an idealized traffic corridor and deterministic queuing methods, the study identifies conditions under which route guidance information is useful, and estimates its benefits in nonrecurring congestion, or incident conditions.

Research suggests that the benefits of route guidance are likely to be marginal under conditions of recurrent congestion. Experienced travelers, who make up the major portion of peak-hour traffic, have sufficient information to manage their route choice. ATIS will probably be more useful under conditions of non-recurring congestion, as may be caused by incidents. Under these conditions, the lack of information about the location, severity and duration of an incident would leave the traveler insufficiently informed to make appropriate route choice decisions. Furthermore, by providing ATIS information to potential travelers before they near incident locations, it may be possible to reduce incident impacts by altering path and departure time choices, thereby spreading traffic over time and space.

This paper presents a simple model that evaluates ATIS benefits. The model is applied to an idealized corridor composed of two routes under off-peak incident conditions. Information on user-optimal travel times is disseminated in real-time to equipped vehicles. When an incident occurs, the ATIS diverts all equipped vehicles to the alternate route until a travel time equilibrium is achieved. Once equilibrium is achieved, it is maintained by reducing the rate of diversion from one route to the other. Deterministic queuing methods are used to analyze queue evolution with and without the ATIS.

The study results show that, following an incident, guided traffic is substantially better off than unguided traffic during the diversion period that precedes the establishment of an equilibrium between the main and diversion routes. However, this advantage is drastically reduced when a queue forms on the alternate route. The benefits to guided traffic are insensitive to the fraction of vehicles equipped with ATIS as long as this fraction is below the critical value that causes a queue on the alternate route. The critical fraction is equal to the ratio of the capacity of the alternate route to the corridor demand, and varies from zero to one. It equals zero when there is no alternate route. It equals one in corridors with several major arterials, usually parallel to the main facility, that can absorb the corridor demand without being congested.

When the alternate route is congested, the benefits to guided traffic become sensitive to the fraction of vehicles equipped with ATIS. The benefits to guided traffic decrease while the benefits to unguided traffic increase with this fraction. Thus, as the proportion of guided traffic increases, the difference in benefits between guided and unguided traffic narrows. System benefits increase with the proportion of guided traffic as long as it is below the critical fraction, but do not increase with this proportion when a queue forms on the alternate route. The findings imply that if the system management has the choice, there is no need to equip more than the critical fraction of the vehicles with ATIS.

It is important to have a reasonable estimate of the critical fraction so that traffic engineers can determine how to operate their system optimally under incidents without over-diverting traffic to city streets. The critical fraction depends on two corridor parameters: the capacity of the alternate route, and the travel demand in the corridor. This study did not analyze incidents that occur during the peak period. During the peak period, the alternate routes are usually congested. If an incident occurs during the peak period and ATIS vehicles are diverted, they join the existing queues on the alternate routes. Therefore, system benefits during the peak conditions are reduced because of the disadvantage caused to travelers originally using the alternate routes where guided traffic is diverted. It was concluded that system benefits under the off-peak conditions represent an upper limit for the benefits of en-route guidance. During the peak period, however, the alternate routes are usually congested, and consequently there is a need to spread traffic over time rather than space.

Allen, R. W., Stein, A. C., Rosenthal, T. J., Ziedman, D., Torres, J. F., and Halati, A. "A Human Factors Study of Driver Reaction to In-Vehicle Navigation Systems." *Future Transportation Technology Conference and Exposition*, Portland, Oregon, 83-102.

Allen, R. W., Stein, A. C., Rosenthal, T. J., Ziedman, D., Torres, J. F., and Halati, A. (1991). "A Human Factors Simulation Investigation of Driver Route Diversion and Alternate Route Selection Using In-Vehicle Navigation Systems." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 9-26.

Allen, R. W., Ziedman, D., Rosenthal, T. J., Stein, A. C., Torres, J. F., and Halati, A. (1991). "Laboratory Assessment of Driver Route Diversion in Response to In-Vehicle Navigation and Motorist Information Systems." *Transportation Research Record*, 1306, 82-91.

Human factors considerations in human-machine system operation include both system performance as influenced by the behavior of the human operator, and human behavior as influenced by design of the human-machine interfaces. These research deal with the system performance of in-vehicle navigation systems that are intended to help deal with traffic congestion. In developing technology for navigation systems, several important issues arise which are associated with both system performance and safety of operation. The human factors study described in these research focuses on how driver behavior associated with in-vehicle navigation systems affects system performance, rather than issues associated with driver distraction from the primary driving task. The question of interest here is whether navigation systems can encourage drivers to take alternate routes, and divert early to avoid congestion, thus minimizing trip delay and improving overall traffic flow.

The work presented in these papers describes human factor laboratory study research results. The results from the laboratory study are used in a traffic simulation analysis to study the impacts of the various navigation systems on driver route diversions. The laboratory study reported in these papers involved simulating trips using visual and auditory representations of the freeway environment, and computer prototypes of various navigation system formats. The design of the prototype navigation systems and testing procedures took into account human factors design and research principals.

During the in-vehicle navigation simulation, the computer controlled visual and auditory stimuli, and recorded when subjects indicated their desire to divert off the main route. Experimental driving scenarios included attributes of traffic incident severity, time constraints, and trip destination. The simulation computer's VGA display was also used to obtain responses to demographic and opinion questions. The experimental design was subdivided into between group and within group factors. The basic variable of interest was navigation system configuration. It was felt that a given subject could only be expected to master one system configuration in the limited training time available, so different groups of subjects were assigned to each navigation system condition. However, each subject experienced all the driving scenarios. Each of the five subject groups was divided into three age groups for non-commercial drivers plus a commercial driving group that included all ages. Subjects were further categorized according to familiarity with the freeway route, and gender.

The experimental procedures involved subject orientation by the experimenter, computer administration of the pre-test questionnaire, simulation training, experimental testing, and computer-administration of the post-test questionnaire. The computer automatically gathered and stored data in all phases of the experiment. Questionnaire responses, traffic level estimations, diversion decisions, and subject feedback data were all stored.

The results indicated that drivers respond to average speed in making diversion decisions. Fifty percent of the experimental population decided to divert by the time the speed was decreasing as traffic transitioned from free flow to the queue caused by the congestion. Also the total number of drivers/subjects diverting increases with the severity of the congestion. For all congestion conditions, old drivers are the most conservative and least likely to divert. The congestion information and navigation guidance provided by the more advanced systems had significant influence on route diversion decisions, with the advanced map system and route guidance systems providing the best overall performance. The post-test questionnaire results indicated that 50% of the subject population would divert if the travel delay reached 18 minutes.

The results showed a definite advantage in providing congestion information and route diversion guidance to motorists with an in-vehicle navigation system. The congestion and route guidance information allows drivers to anticipate congestion in making route diversions, and results in a greater percentage of drivers diverting to an alternate route. Driver opinion also indicates that they would be most willing to buy an in-vehicle navigation system if it costs about the same as stereo system. The simulation experiment was run under open loop conditions, where the subject’s diversion decision did not influence alternate route congestion.

Allen, P. A. (1993). "Driver Response to Parking Guidance and Information Systems." *Traffic Engineering and Control*, 34(6), 302-307.

This study looks at the effect of parking guidance and information (PGI) systems on driver behavior at a disaggregate level, using a stated preference survey of shoppers who had driven to the local shopping district and parked in an off-street car park. The survey was conducted during weekday working hours in an outer London borough where a PGI system had been in operation for less than a year at the time of the study. The PGI system monitors occupancies at eight car parks in the town center. An outer ring of variable message signs indicates aggregate parking space availability by town area; within an area, variable message signs indicate that particular car parks have spaces, are full or are closed. At the request of the car park operators, nearly full car parks are not indicated by a particular text message, but rather by a blank message; the operators were concerned that an explicit message would be inappropriately dissuasive.

The stated preference surveys proposed two sets of legends, one being the set in use by the operational PGI system, and the other indicating that particular car parks have spaces, are almost full, or have queues of vehicles. Other car park attributes included price per hour and walk time from the park to the destination. The survey posed hypothetical choices between different combinations of parking cost, walking time and message set. From the full factorial design, a subset of eight choice situations was extracted, representing what were felt to be the main attribute effects.

Three demographic groups were targeted: women under 30 years; women 40 to 60 years; and men and women over 60 years. Around 16% of the on-street requests resulted in successful interviews. Many respondents claimed that they did not know about or take notice of the PGI system operating in the area. Quota sampling was employed to obtain 30 usable surveys from each group.

Respondents were found to be equally dissuaded by a "full" and a "queues" message, and to respond strongly to the "almost full" message (confirming the intuition of the car park operators). The sensitivity of choice probabilities to price was relatively weak except among younger women. The sensitivity of choice probabilities to walking time was also relatively weak except among the elderly group. (Values of price and walk time used in the SP experiments were based on minor perturbations of average conditions in the survey area. More significant effects would likely be observed for higher values of cost or walk time.) Display of a "full" or "queues" message had a strong effect on car park choice, but the effect of messages was significant in every case.

Arnott, R., de Palma, A., and Lindsey, R. (1991). "Does Providing Information to Drivers Reduce Traffic Congestion?" *Transportation Research A*, 25A(5), 309-318.

This article is an analysis of the effect of information on drivers' travel costs in the presence of uninternalized congestion. This study models both departure time and route choice using schedule delay as well as travel time costs. Drivers are assumed to commute each morning from a common origin to a common destination connected by two routes. The capacities of these two routes are assumed to be "high" or "low" with a certain probability distribution. Traffic inflow rates that exceed capacity lead to queue formation and delays. Drivers receive pre-trip information about the route capacities so that they can adjust both their departure time and route, if desired. In some analyses, the capacity information is accurate; in others, it is an approximate indication that may or may not be accurate. The paper considers situations in which information is provided to no drivers, to all drivers, and to a single driver. Impacts are measured in terms of total travel costs (or times).

The focus of this article is on one potential source of inefficiency from information systems: drivers who receive common information may tend to make similar route and departure time decisions, thereby increasing congestion. There is no attempt to take account, when providing the guidance information, of the likely reaction of drivers to the guidance itself. This is related to the assumption that congestion is under-priced. If guidance does not take account of driver reactions, but driver behavior is based on the correct marginal costs, this inefficiency would be reduced or eliminated. If guidance is based on average costs (as it is here) but does take account of driver reactions to it, the inefficiency would be reduced but not eliminated.

The analysis is complex and the results difficult to summarize. One intuitively clear finding is that the quality of information is an important determinant of its travel time impacts. More generally, the study can be viewed as an investigation of some of the adverse impacts that may occur when guidance is generated without taking into account its effects on travel conditions.

Barfield, W., Haselkorn, M., Spyridakis, J., and Conquest, L. (1989). "Commuter Behavior and Decision Making: Designing Motorist Information Systems." Proceedings of the Human Factors Society 33rd Annual Meeting, 611-614.

Haselkorn, M., Spyridakis, J., Conquest, L., and Barfield, W. (1989). "Surveying Commuter Behavior as a Basis for Designing Motorist Information Systems." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 93-100.

Haselkorn, M., Barfield, W., Spyridakis, J., and Conquest, L. (1990) "Understanding Commuter Behavior for the Design of Motorist Information Systems." *Transportation Research Board 69th Annual Meeting*.

Wenger, M. J., Spyridakis, J., Haselkorn, M., Barfield, W., and Conquest, L. (1990). "Motorist Behavior and the Design of Motorist Information Systems." *Transportation Research Record*, 1281, 159-167.

Spyridakis, J., Barfield, W., Conquest, L., Haselkorn, M., and Isakson, C. (1991). "Surveying Commuter Behavior: Designing Motorist Information Systems." *Transportation Research A*, 25A(1), 17-30.

Conquest, L., Spyridakis, J., Haselkorn, M., and Barfield, W. (1993). "The Effect of Motorist Information on Commuter Behavior: Classification of Drivers into Commuter Groups." *Transportation Research C*, 1(2), 183-201.

Mannering, F. L., Kim, S.-G., Barfield, W., and Ng, L. (1994). "Statistical Analysis of Commuters' Route, Mode and Departure Time Flexibility." *Transportation Research C*, 2(1), 35-47.

These papers concern a driver survey conducted in Seattle by the University of Washington in September 1988, and subsequent analyses of it. The intent of the survey was to obtain information about driver departure time and route choice behavior, and particularly about the influence of traffic information (primarily from commercial radio and television traffic announcements and variable message signs but also from highway advisory radio and telephone information services) on this behavior. The survey consisted of a large sample mail-in questionnaire distributed to drivers on Interstate 5 (nearly 4,000 completed responses), followed by a smaller set of personal interviews (96 subjects, selected at random from within groups identified during the analysis of the first set of results). (Wenger, Spyridakis et al. 1990) deals particularly with the results and analysis of the personal interviews, whereas the other papers describe more generally the organization of the overall survey effort and the results and analysis of the questionnaire component. Most of the analyses relied on multivariate descriptive statistical methods except for (Mannering, Kim et al. 1994), which estimated behavioral models.

Questionnaire topics concerned characteristics of the daily commute trip; flexibility with respect to departure and arrival times; familiarity with the network; frequency of tripmaking decision modifications; influence of various factors on route choice; use of, preference for and assessment of various sources of pre-trip and en route traffic information; response to traffic information; preference for various types of improved traffic information services; and basic socio-economic characteristics. In all, data on 62 variables were collected.

The questionnaire data were analyzed in various ways, but of particular interest here is a cluster analysis intended to identify subgroups of respondents distinct with respect to their travel behavior and use of traffic information. Four clusters were identified:

- time and route changers (40%): those willing to change both departure time and commuting route;

- non-changers (23%): those unwilling to change departure time, transportation mode or commuting route;

- route changers (21%): those willing to change their commuting route on or before entering the Interstate; and

- pre-trip changers (16%): those willing to make time, mode or route changes before leaving the house, but unwilling to change once they were en route.

A particular driver's association with one of these groups might be a result of specific constraints (e.g., a requirement to leave home at a particular time in order to drop off children at school), but was also related to socio-economic characteristics.

A principal components factor analysis was also performed on the questionnaire data set. Five factors, accounting for around 33% of the variance, were extracted from the correlation matrix. The factors related generally to route choice issues; commuting distance and time characteristics; attitudes towards and use of commercial TV and radio traffic information; attitudes towards and use of HAR, VMS and telephone-based traffic information; and commuter characteristics and flexibility.

The in-depth interviews selected subjects at random from each of the four clustered identified above, in numbers proportional to the original cluster sizes. They investigated three broad areas of interest, based on the analysis of the questionnaire responses (all questions concerned the morning commute only):

- behavior and decisions of commuters relative to their route choice before departure. These questions probed the respondents' pre-trip time and other constraints due to morning activities; their degree of flexibility in departure time scheduling; their access to and use of traffic information; and their specific route, mode and departure time choices;

- behavior and decisions of commuters while driving. These questions concerned behavior and decisions during the commute between home and work. The respondents' knowledge of the network was assessed, and the principal re-routing decision points were identified. Respondents were asked to report their reasons for switching routes at each decision point. Other questions examined the use of information (including subjective observations of traffic conditions) in making route switch decisions and in confirming or refuting such decisions; the amount of flexibility with respect to arrival time and late arrival penalties; the stress encountered when using alternate routes; and the number of times each month the respondent arrived late for work because of traffic conditions; and

- stated responses of commuters to particular VMS messages and their variations. One set of variations concerned specific vs. generic recommendations ("use route XYZ" vs. "use alternate route"). The other concerned specific or generic reasons given in a message ("accident at location XYZ" vs. "accident ahead") and its association or not with a recommended task ("do something specific" vs. "expect delays").

A complex but coherent picture of commuters and their travel and information-response behaviors emerges from these surveys.

With regard to the pre-trip context, most people reported not being stressed or constrained by many activities. While a large majority receives traffic information of some kind before leaving, there is often a long time lapse between receiving it and actually departing. A majority also reported that pre-trip information rarely had an effect on their choice of departure time (64%), mode (90%) or route (66%). These findings may indicate that traffic information is perceived as not credible, either by its very nature or because of the time that passes between receiving it and actually starting on a trip. Furthermore, the findings indicate that most people would have time available to use a traffic information system that required an active engagement.

With regard to en route behavior, commuters were generally well informed about route alternatives and on occasion use them. Small adjustments to the usual route were generally based on observations of traffic conditions, while shifts to alternative routes were generally made on the basis of traffic reports. However, commuters rarely receive feedback about whether the choice that they made was correct or not. The implications are that commuters would benefit from more current and more specific information than that available from radio traffic reports, and would also benefit from feedback regarding the correctness of their decisions.

With regard to the VMS message design, subjects were more likely to correctly interpret a message when it recommended a specific rather generic task, and when a reason was given before the task. In contradiction to this, however, they indicated that they would be more likely to change their route when the message recommended a generic task, and presented the task (rather than the reason) first. They further indicated that they would be most likely to change route if the message presented a generic reason and did not present a task at all. Further investigation of these results would seem to be warranted.

(Mannering, Kim et al. 1994) used the data set to estimate a number of behavioral models. First, the authors estimated an ordered probability model of the propensity to change routes. An ordered model was appropriate because respondents only indicated if they changed routes frequently, sometimes or rarely, rather than stating their actual number of route changes; an ordered model takes account of the fact that the "sometimes" choice implies a greater frequency than the "rarely" choice. Ordered logit and ordered probit models were estimated, but the results were statistically indistinguishable. Most of the effects that would be expected a priori were found: for example, factors increasing the propensity to switch routes included greater commute distance, estimated delay on the current route, and familiarity with alternative routes. Interestingly, the significant variables in the home-to-work and work-to-home directions varied somewhat.

Next, the authors considered the level of traffic delay that causes commuters to switch to an alternative route. They estimated a proportional hazards model expressing the switching hazard function (the conditional probability that a particular level of traffic delay will cause a route switch, given that lesser levels of delay have not caused a switch) as a function of a number of trip and socio-economic characteristics. It was found that greater delays were required to produce a route switch when the average commuting speed and time were higher. Both flexibility of departure times and familiarity with alternate routes decreased the delay required to produce a switch.

Finally, the authors investigated the effect of pre-trip information on travel choice. The survey asked respondents how often such information caused them to change some aspect of their travel behavior (frequently, sometimes, rarely and never). As in the analysis of similar data described earlier, an ordered probability (logit) model was utilized to model the responses. Separate analyses of the effect of pre-trip information on departure time, mode and route choice were made.

Ben-Akiva, M., Bergman, M. J., Daly, A. J., and Ramaswamy, R. (1984). "Modeling Inter-Urban Route Choice Behavior." Proceedings of the 9th International Symposium on Transportation and Traffic Theory, 299-330.

This paper examines route choice behavior with the objective of gaining a better understanding of drivers' route choice preferences in order to improve traffic assignment procedures. It hypothesizes that drivers' route choice behavior is affected by general factors: their knowledge of alternative routes, their route choice decision processes, and the actual route attributes and driver preferences. This paper attempts to incorporate these hypotheses within a discrete choice modeling framework.

Direct application of discrete choice modeling methods to route choice behavior, however, is often not feasible because of the size and complexity of the choice set: there are usually a very large number of feasible routes between an origin and a destination, and these routes overlap in complex ways. The paper treats these difficulties by developing a model structure that consists of two stages: choice set generation followed by selection from the choice set.

The data set used for model estimation was collected in the area between Utrecht and Amersfoort in the Netherlands. In this area, drivers are confronted with a variety of feasible paths, rather than being "captive" to one clearly superior path. Data on the routes chosen by the drivers were taken from a survey that was conducted during 1979.

In the first stage of the model, a labeling approach is used to replace consideration of the huge number of feasible routes by consideration of a much smaller number of routes, each embodying a special criterion that might be relevant to route choice. These criteria (minimize time, minimize distance, maximize scenery along routes etc.) are the labels. For each label, a criterion (or a generalized impedance) function is defined so that a network minimum path algorithm can be used to build trees containing paths that emphasize the label characteristics. For example, for the scenery label, time spent on roads with poor scenery would be much more highly weighted (have greater impedance) than time on scenic roads. In designing and selecting labels, the objective is to generate a reasonable set of paths that include the actual paths chosen by the drivers. The objective function of the entire label set is to maximize the coverage by the label set of the set of chosen paths, and the optimal values of the parameters of the impedance functions are the values that maximize this coverage. A deterministic choice set generation model is estimated for this purpose.

In the second stage, a model of choice from the set of labels is applied to predict the chosen route. A discrete choice model having nested logit form is used. The utility function of a physical path includes vector of variables (generic path attributes like time and distance) describing the physical path, dummy variable and associated vectors of unknown parameters.

The model formulation was too complicated to be estimated using available software. Estimations were made with a series of successively less severe restrictions imposed on the general model.

The estimation results showed that time and distance have major and significant roles as determinants of route choice. Other attributes such as scenic time, high capacity and highway distance were also demonstrated to affect route choice. The model results indicated that the disutility of travel time on a non-scenic road is about five times the disutility of scenic travel time and the disutility of distance on a minor road may be as high as six times the disutility of distance traveled on a high standard expressway. The value of time implied by the model varies depending on the road characteristics. The empirical results indicate that factors other than time and distance play a significant role in inter-urban route choice behavior.

Ben-Akiva, M., de Palma, A., and Kaysi, I. (1991). "Dynamic Network Models and Driver Information Systems." *Transportation Research A*, 25A(5), 251-266.

This paper develops a dynamic network modeling framework that can be used to generate predictive information for a dynamic route guidance system and to predict the effects that travel decisions by informed drivers may have on overall traffic conditions. The approach builds on a number of prior analyses of traffic modeling needs for driver information systems. It is based on a dynamic network modeling framework that incorporates a driver behavior model and a network performance model. The framework explicitly treats the distribution of traffic by time of day, and also represents drivers' pre-trip and en route adjustment processes. It extends prior work by incorporating drivers' acquisition and processing of traffic information. The objective of the extended framework is to capture the potential effects of driver information messages on individual driver behavior as well as on overall traffic conditions.

The paper identified three potential adverse impacts of driver information:

- oversaturation occurs when the amount of information a driver receives is too great to be effectively processed into a rational decision in the time available to made the decision. The general problem of information oversaturation is exacerbated in a driving context because of the accident-producing potential from driver distraction or confusion. In practice, the need to avoid oversaturation limits the amount and complexity of information that can be provided by messages to drivers;

- overreaction occurs when a significant number of drivers receive identical messages and react in roughly the same ways. This could cause congestion to transfer from one route to another or even produce oscillations in path flows; and

- concentration occurs when driver information reduces the natural variability of individual drivers' decisions and leads them to act similarly, possibly leading to congestion increases.

Dynamic driver behavior modeling is the principal focus of the paper. The authors propose a modeling framework consisting of: goal formation; information acquisition; driver information processing capacity and computational ability; decision rules; reviewing; and actual decision.

In the context of repetitive travel, drivers' dynamic behavior can be represented by a hierarchy of pre-trip and en route choices. The potential pre-trip choices are:

- integrate previous the previous day's experience and information with historic perceptions in order to update the historic perceptions;

- before departing from the trip origin, acquire and process the current day's traffic information;

- decide whether or not to reconsider habitual departure time and route choices;

- if reconsidering, acquire and process further information; and

- if reconsidering, decide on the current day's departure time and route.

Once a trip begins, a driver automatically receives new information about the choices he or she made, and this may lead to a decision to reconsider the choices (route choice in particular). If reconsidering, further information may be acquired and processed, and a route switch decision may be made. This procedure is repeated until the destination is reached.

The authors formulate a mathematical model of the day-to-day adjustments in travel demand as well as the (mostly pre-trip) information acquisition process. However, the model is very general and they do not derive any definite conclusions from it. They identify a number of policy issues which could, in principle, be addressed with the model. The issues are sufficiently general to be pertinent in any guidance system modeling and design exercise:

- how many drivers should receive guidance? (There is some evidence from analytical and simulation studies that, beyond a certain market penetration, benefits of guidance decrease with increasing numbers of informed drivers);

- how should information be provided and used?

- how predictive should the information be?

Ben-Akiva, M., de Palma, A., and Kaysi, I. (1996). "The Impact of Predictive Information on Guidance Efficiency: An Analytical Approach." Advanced Methods in Transportation Analysis, L. Bianco and P. Toth, eds., Springer-Verlag, 413-432.

From the abstract:

"The acceptance of route guidance advice by motorists is expected to occur only whenever such advice is experienced to be valid and reliable. Three major factors may cause route guidance systems to provide motorists with unreliable advice:

- the traffic information constituting the basis for the guidance is inaccurate;
- the impact of a large fraction of motorists responding to the guidance, and the subsequent overreaction that occurs, is ignored whenever the guidance advice is being set; and
- concentration effects may occur and induce a higher level of (unpriced) congestion when drivers are provided with better information.

In this paper, the impact of the above factors is investigated for a small prototypical network. We provide numerical and analytical results in order to identify the critical factors involved in the design of driver information systems. The analysis presented in the paper involves (a) estimating the benefits of accurate predictions of traffic conditions; (b) assessing the sensitivity of guidance provision to inaccuracies and imperfections in the traffic predictions; and (c) comparing the behavior of uninformed drivers with that of drivers receiving myopic or predictive guidance."

The network considered by the authors has three origins and one destination. Traffic from one of the origins can split, in response to guidance, between two alternative paths. Once a path is chosen, there is no possibility of further switching. Traffic from each of the other origins has only one of the paths available to it. Network performance is modeled via deterministic queues at the nodes. The authors investigate the impacts of different procedures for setting the splitting rates for traffic leaving the first origin. Comparing instantaneous travel times and predictive travel times for this purpose, the authors find that (1) while total travel time is only reduced slightly by basing guidance on predictive rather than instantaneous information, the latter type of information results in large discrepancies between travel times on the two alternative paths; (2) the superiority of predictive travel time over instantaneous information is robust with respect to the quality of required flow predictions; and (3) when the day-to-day variations in traffic flow are not large, uninformed drivers may be better off then drivers who received guidance based on instantaneous traffic conditions. However, in this case predictive guidance offers only marginal improvements over the no-information case as well.

Bonsall, P., and Parry, T. (1990). "A Computer Simulation Game to Determine Drivers' Reactions to Route Guidance Advice." Proceedings of the 18th Planning and Transport Research and Computation (International) Co. Summer Annual Meeting, London, 113-124.

This paper describes the development of a computer-based simulator for obtaining data on travel choice decisions in the presence of information. The simulator is called IGOR (Interactive Guidance on Routes).

IGOR invites test subjects to make a series of journeys through a small network (30 links and 19 nodes) that representation a typical small town whose network offers a number of interesting route choice options. Users select their own routes from specified origins to specified destinations. Each link has a basic traversal time, but its actual time during a run depends on assumed weather conditions, time of day, and random variability in traffic conditions. As a journey progresses, IGOR displays an annotated plan of each intersection, showing the alignment and road type (freeway, major, minor) of each exit together with information on:

- the amount of congestion (if any) visible on each exit link;
- which exit link (if any) is recommended by road signs for the destination;
- the amount of traffic turning into each of the exits.

The user then selects the preferred exit from the intersection. There is no constraint on the amount of time allowed for taking this decision. After an interval of time proportional to the time that would actually be required to traverse the chosen link, a display of the next intersection is provided, and so on to the destination. For some experiments a map of the network is available, while for others the network was completely unknown. Traffic conditions in the simulated network vary from one run to another. After a few runs have been completed, the user is informed that the system will thereafter make route recommendations at each intersection but that the user is free to accept or reject the advice. Most users receive perfect (travel time minimizing) recommendations, but the guidance system is assumed not to take account of secondary links, and in some cases it provides intentionally degraded advice which, if followed, would direct drivers to routes that are about 10% longer on average than the theoretical minimum.

The circumstances faced and the advice received by each driver at each intersection are recorded along with the driver's decision. Information about driver characteristics and attitudes towards route choice and guidance is also collected via an interactive interview carried out before the runs begin. A typical session, involving nine runs through the network, lasts 30 to 40 minutes.

Bonsall, P., and Joint, M. (1991). "Driver Compliance with Route Guidance Advice: The Evidence and its Implications." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 47-59.

Bonsall, P., and Joint, M. (1991). "Evidence on Drivers' Reaction to In-Vehicle Route Guidance Advice." Proceedings of the ISATA Conference, Florence, 391-401.

Bonsall, P., and Parry, T. (1991). "Using an Interactive Route-Choice Simulator to Investigate Drivers' Compliance with Route Guidance Advice." *Transportation Research Record*, 1306, 59-68.

(These papers cover very similar material. The first two are essentially identical. The third discusses the results of travel choice simulation experiments conducted in 1990 using IGOR, but these results are covered at the same level of detail in the other two papers as well. For this reason, the three papers are reviewed together here.)

The papers present results on drive compliance with route guidance advice from two sources: questionnaires conducted among drivers equipped with route guidance as part of the (West) Berlin LISB in-vehicle guidance system trial, and analysis of decisions made by users of the IGOR interactive route guidance simulator (Bonsall and Parry 1990).

LISB is the name given to the Berlin deployment in the late 1980s and early 1990s of the Siemen's Ali-Scout dynamic in-vehicle guidance system (Ali-Scout is also the basis of Michigan's FAST-TRAC operational test). It provides drivers with advice on minimum time routes to specified destination via an in-car display screen and synthesized voice messages. User must first key in the code or grid reference of their intended destination. A small screen then displays the direction and distance "as the crow flies"; this is called the autonomous mode. When the vehicle first passes a roadside beacon, the in-vehicle unit receives information that allows it to inform the driver (via graphical and audible messages) of the movement to make at each intersection; this is called the full guidance mode. Towards the end of the journey the system reverts to autonomous mode because the density of beacons may not be sufficient to provide detailed local area guidance. When LISB began operation, the guidance was static, i.e., based only on average traffic conditions for the time of day. Later, however, the system began to generate dynamic guidance. Actual traffic conditions were estimated from historical data and recent link traversal time records transmitted by LISB-equipped vehicles on the network. These real-time conditions were used as the basis for route recommendations.

Analysis of LISB user behavior based on self-completion questionnaires administered at different phases of system usage show a high level of commitment by participants in the trial but nevertheless indicate a general reduction in usage of the equipment over time. Static guidance was found to be particularly unhelpful in incident conditions (not surprisingly), although some respondents mentioned that they had discovered new routes to familiar destinations as a result of it. Dynamic guidance was felt to be an improvement over static guidance and about 90% of drivers normally (though not invariably) requested its advice even when driving in familiar areas. Drivers would reject guidance because they thought it was sending them in the wrong compass direction, because it was given too late, because it suggested that they leave a route which appeared to be good or divert to a route which was normally congested, or because of doubts that the system was functioning correctly.

Compliance with routing advice was not high on regular journeys and reflects a low opinion of the quality of routes recommended by the system for such journeys. For finding new destinations or traveling in unfamiliar areas, opinions and usage were much higher. After six months of using LISB, 65% of respondents generally expected the system to save them time when traveling in unfamiliar areas, but only 47% expected it to same them time on the journey to work. Overall driver behavior was not much influenced by LISB.

The IGOR travel choice simulator was used in 1990 to conduct experiments on around 350 individuals in England and France; the collected information involved around 13,000 route choice decisions. On average, 27% of the items of advice were rejected and only 35% of the trips were made in total compliance with all advice. It was found that compliance depends on the extent to which the advice is corroborated by other factors such as the coincidence between the recommended direction and the compass direction towards the destination, or the amount of congestion visible on the recommended intersection exit. It clearly varied with the overall quality of the advice (as measured by the ratio of the minimum time to destination via the recommended intersection exit to the minimum time via the optimum exit). The quality of advice previously received by a driver was also an important determinant of his or her compliance with a new recommendation: drivers who had received nothing but optimum route recommendations would tend to accept even incorrect recommendations, whereas those who had previously received poor advice were more discriminating. Detailed analysis showed that the quality of the most recent prior recommendations had a stronger effect on compliance than the quality of earlier recommendations. Compliance was highest for journeys made in a network that had not been previously visited, and for which no map was available; it fell as drivers became more familiar with the network through repeat experiments. Finally, individual driver characteristics also influenced compliance behavior: younger drivers, and drivers with high levels of driving experience were more likely to reject route recommendations. Nonetheless, there remained a residual which could not be linked to any particular explanatory factor.

The main conclusions are that drivers are unlikely to request guidance if they find the effort of doing so out of proportion to their perceptions of the benefits to be gained, and that they are likely to reject guidance if they do not find it credible. Factors affecting credibility include:

- the extent to which it is corroborated by, or contradicted by, local evidence about the route alternatives and their traffic conditions;

- mismatch between the system's route choice criteria and those of the driver;

- the driver's familiarity with the local network;

- the quality of advice previously, and particularly very recently, received from the system by the driver; and

- the driver's general predisposition to accept or reject advice.

Bonsall, P. (1992). "Research Methods for the Study of Driver Response to In-Vehicle and Roadside Guidance Methods." Selected Proceedings of the 6th World Conference on Transport Research, Lyon, 2519-2530.

This is a review of possible methods for studying drivers' responses to advanced traveler information systems. It argues that different techniques are appropriate to different stages in the process of designing, refining and evaluating a system, and that the choice of method will also depend on the types of question being asked and the type of system being investigated.

Among the methods considered are:

- pre-implementation stated preference methods, in which potential users are asked how they would react to hypothetical choice situations involving a not-yet implemented system. Despite the obvious limitations of this kind of approach, such exercises can be effective in the project pre-design phase;

- pre-implementation studies using simulators. Simulators include realistic full-scale automobile mock-ups that faithfully replicate the driving experience using interactive multimedia; and part task simulators that focus specifically on factors relevant to route choice decisions in the presence or absence of information, excluding other aspects of driving. Examples of the latter are the route choice simulator IGOR (discussed above), and systems such as the STI simulator and FASTCARS. The author argues that, despite their relative lack of realism, such systems are effective ways of collecting large amounts of data about driver route choice decision making;

- on-road trials using prototype equipment. These methods are available when a prototype of an in-vehicle system exists, so that drivers' reactions to it can be observed in the context of real journeys. Human factors and interface design questions can be carefully studied with such methods. Because the number of available prototypes is generally small, the amount of data collected by these methods is not suitable for use in analyzing statistical issues such as route choice behavior;

- post-implementation studies, which are available once a system has been deployed and a population of users has become familiar with it. Possible studies include observations of individual driver behavior and analyses of aggregate network-level impacts.

  – Systems that have been appropriately designed are capable of collecting considerable information on the way drivers make use of them. However, this approach raises serious privacy issues and there may be limitations on the extent to which the system can collect data on external factors and on non-chosen alternatives. Of course, users can be interviewed regarding their use of and experience with the system, but the quality of the obtained data may be suspect.

– When a large population of users has been exposed to a particular system it will generally be cheaper to measure aggregate impacts than to examine individual behavior and to aggregate this using models. System impacts can only be deducted by comparing with- and without situations, generally involving a before-and-after study. Unfortunately, easily-measured indicators of route choice changes, such as link flows downstream from a route divergence point, are generally made complicated by the variability in traffic levels and noise in its measurement. Furthermore, interpretation of such data to determine the effectiveness of the system may require knowledge about the specific characteristics (e.g. destination) of potentially affected trips, knowledge which is not generally available.

Bonsall, P. (1992). "The Influence of Route Guidance Advice on Route Choice in Urban Networks." *Transportation*, 19, 1-23.

The paper is concerned with the impact of ATIS systems on route choice. It paper begins by reviewing what is known about route choice processes and notes the mismatch between this knowledge and the route choice assumptions embedded in the most widely used traffic assignment models.

For interurban trips, it has been observed that between 75% and 90% of route choice decisions are made on the basis of time or distance minimization. However, a significant number of interurban travelers simply follow main roads or those with road signs, perhaps because they are unfamiliar with the network. Urban route choice criteria are much less clear; some researchers have concluded that time minimization is the dominant criterion, while others have noted the importance of other criteria such as road type (freeway or other, for example), avoidance of congestion or of traffic controls. Congestion avoidance and arrival time reliability are claimed to be more important than time minimization for many drivers. In contrast to this, most traffic assignment models simply assume that drivers seek to minimize travel time or generalized cost (a weighted combination of time and distance).

Empirical evidence on the influence of route guidance advice on route choice is reviewed and, despite its limited nature, is seen to suggest that users are reluctant to follow advice unless they find it convincing and that, the more familiar they are with the network, the less likely they are to accept advice. In limited or informal studies of driver response to VMS in the context of parking advice and congestion avoidance systems, as well as of radio broadcast reports and in-vehicle ATIS systems (LISB in Berlin), it was found that drivers rarely follow route recommendations without question. Reasons given for ignoring some or all of the advice vary considerably: some ignore it because they feel it to be unreliable, others feel that they have better knowledge of routes through side streets, while others deliberately do the opposite of what is recommended in order to "avoid the crowd". Typically only a small minority of journeys are made in total compliance with advice. However, the paper notes that these results are not sufficiently quantitative to allow estimation of models of driver behavior in response to guidance.

Results from an interactive route choice simulator (IGOR) (Bonsall and Parry 1990) are summarized. Experiments conducted in England and France collected information on around 13,000 decisions. On average, 27% of the items of advice were rejected and only 35% of the trips were made in total compliance with all advice. It was found that compliance depends on the extent to which the advice is corroborated by other factors, on the drivers' familiarity with the network and on the quality of advice previously received. The IGOR results are in a form which would enable response models to be calibrated, although no such model is presented in the paper.

The paper discussed a number of approaches to the network-level modeling of route choice in the context of ATIS. Such models must clearly distinguish between guided and unguided drivers. Using static assignment models, a common approach is to assign trips by both groups using a stochastic user equilibrium (SUE) method, but assuming that unguided drivers have a higher variance than guided drivers. Another approach is to assign unguided drivers based on uncongested costs and guided drivers based on actual costs. Yet another is to assign unguided drivers based on an "average" user equilibrium solution, then to perturb the solution (to reflect variability in traffic conditions) and assign guided drivers based on the actual conditions. All of these approaches involve simplifying assumptions which limit the relevance of their results; most make no allowance for the fact that drivers are unlikely to comply with all advice and several are not able to represent the benefits which guidance might bring in the context of sporadic congestion or incidents.

As an alternative, the authors propose a model system that attempts to provide a realistic representation of:

- route choice by unguided drivers;
- drivers' reactions to network conditions on specific days;
- the specific characteristics of the ATIS deployment; and
- guided drivers' acceptance or rejection of route recommendations.

From these requirements, the authors conclude that the model system should be based on dynamic traffic simulation. It would include different driver groups, each with its own route choice criteria. The model is run in two phases in order to distinguish between strategic route planning and the tactical adjustments made in response to ATIS messages and actual road conditions. The first phase simulates average traffic conditions while the second phase simulates actual conditions on a specific day. Traffic modeling in the second phase would use a microscopic simulation of individual drivers, including a model of response to en route information and conditions. Route reconsideration would be triggered when the difference in perceived costs between the currently-followed route and an alternative exceed a threshold that reflects switching inertia. If reconsideration takes place, the choice would then be deterministic.

At the time of the paper, the authors were beginning the implementation of such a model.

Bonsall, P., Firmin, P., Anderson, M., Palmer, I., and Balmforth, P. (1997). "Validating the Results of a Route Choice Simulator." *Transportation Research C*, 5(6), 371-387.

This paper describes the validation of a route choice simulator known as VLADIMIR (Variable Legend Assessment Device for Interactive Measurement of Individual Route choice), which is the successor to the IGOR simulator described above.

Like IGOR, VLADIMIR is an interactive computer-based tool designed to study drivers' route choice behavior. However, VLADIMIR differs from IGOR in being able to represent real-world networks and in having a much more realistic user interface. The simulator uses a sequence of digitized photographs (typically on the order of 800 separate photographs) to portray an actual regional-level network with junctions, links, landmarks and road signs. Different types of ATIS messages are realistically represented: for example, roadside VMS messages can be made to appear through the simulated windshield, while in-vehicle messages can be made to appear on the simulated dashboard. Although some versions of the simulator also included a proxy steering task (to represent the fact that drivers cannot devote all their attention to navigation), this was found to be too distracting to the experimental subjects and was finally eliminated.

The VLADIMIR display depicts a realistic street scene on which are superimposed a sketch diagram of the local network and turn options, an indication of traffic conditions, simulation-specific data (such as the elapsed time and distance since the previous scene change), and a representation of dashboard instruments (speedometer, odometer and clock). Drivers indicate their intersection movement decisions using computer keys, and the windshield view updates accordingly at a rate determined by the prevailing traffic speed. If a driver takes too long to make a decision at an intersection, a simulated horn beeps after a few seconds.

Subject drivers are invited to make trips between specified origins and destinations under a range of travel scenarios, during which the simulator automatically records their route choices. Prior to each trip, the driver is given context information including the trip purpose, departure time, importance of desired arrival time, day of week, time of year and local weather conditions. At the end of each trip, the subject is asked whether he or she felt confident that the route driven in the simulation was the same as the one that would have been chosen in equivalent conditions in real life. After completing all their runs, drivers are questioned about their route choice criteria and socio-economic characteristics. A typical experiment lasts around 40 minutes.

The paper describes validation experiments carried out during the period summer 1994 to autumn 1995 and reports on the results obtained. Each experiment involved a comparison of routes selected in real life with those driven under simulated conditions in VLADIMIR. The analysis included investigation of the subjects' own assessment of the realism of the VLADIMIR routes they had chosen, a comparison of route choice models based on the real life routes with models based on VLADIMIR routes, and a statistical comparison of the two sets of chosen routes.

It was found that, with careful preparation of the VLADIMIR network, subjects in experiments without ATIS messages are confident that their simulated route choices are highly realistic (i.e., reflect the choices they would have actually made on the road). This stated confidence is much lower for trips made with guidance, although some of the reduction may be due to unfamiliarity with, or lack on trust in, the guidance itself.

Route choice models (simple multinomial logit specifications involving variables such as travel time and the geometric alignment of a recommended route with the currently followed route) were estimated from actual route choices of VLADIMIR experimental subjects, simulated route choices they made using VLADIMIR, and combined data sets. It was found that, for the same set of drivers, models estimated from actual and simulated route choices were virtually identical. For a different set of drivers, the estimation results are somewhat different, but the error in the VLADIMIR-based model is barely different from that in the real-life data. Performance is improved by eliminating from the data sets those choices which subjects had declared to be unrealistic.

Despite some difficulties in finding strictly comparable choice situations, a comparison of simulated and actual route choices (54 comparable situations) showed identical results in 87% of the cases. Close examination of the differing routes indicated that the differences were consistent with daily route choice variations and with slight differences in the choice contexts (e.g., time of day). Drivers with good network knowledge and a propensity to change routes by time of day did so both in the simulator and in their actual driving.

The overall conclusion is that with a realistic and comprehensive network database and a willingness to discard data that is not vouched for by the subjects, real world route choice behavior is replicated in VLADIMIR with considerable accuracy. Routes which subjects chose in the simulator are virtually identical to those which the same subject choose in real life. Similarly, where subjects are unfamiliar with the network, they make the same kinds of errors (sub-optimal route choices, missed turns) that people make in real life in similar circumstances. Furthermore, similar strategies are seen to be used to make the best use of limited network knowledge (e.g., detouring in order to link up with a known route).

The key simulator design features that contribute to this quality would seem to be:

- a user interface that clearly separates in- and out-of-vehicle visual stimuli;
- a means of enabling subjects to situate themselves in the network without giving more clues than would be available in actual driving situations;

- a realistic representation of penalties for driving in slow traffic or making complex maneuvers;
- a realistic context scenario for each trip; and
- a simple user interface.

Bonsall, P., and Palmer, I. (1999). "Route Choice in Response to Variable Message Signs: Factors Affecting Compliance." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 181-214.

The paper both surveys results from previous studies and presents some new results on factors that influence drivers' compliance with VMS messages related to route choice. It includes:

- a discussion of data collection methods (similar to that in (Bonsall 1992b));

- an analysis of the characteristics of effective VMS messages. Primary requirements are that messages should be visible, legible and understandable. Many design guidelines treat the first two issues. The issues associated with ensuring that (necessarily brief) VMS messages are understandable are much more complex and less well researched. Issues include acceptable abbreviations, reliance on knowledge of the local network, and choice of phrases used to describe incident cause, effect and/or location;

- evidence (based on VLADIMIR route choice simulation studies in three regions) on the effectiveness of different message types, formats and contents. Prior evidence suggests that messages have the greatest effect if they combine routing advice with descriptive information about an incident. It has also been found that giving advice without information is generally less effective than giving information without advice, contingent on specifics relating to the strength of the advice and the nature of the information.

  Advice that gives clear instructions for an immediate action receive higher compliance than more nebulous advice. An instruction that specifies a nearby problem location is more likely to be followed than one that does not.

  Accurate quantitative information on the effects of a problem (e.g., extent of delays) is preferred to a qualitative description of the effect or a mention of the cause. Most studies have found a strong relationship between the diversion achieved and the extent of reported delay; some researchers have found that 1 minute of delay reported on a VMS sign had the same effect as 1.75 minutes of normal trip time. However, mentioning very small delays sometimes produces less diversion than not including delays at all in the message. The effects of providing qualitative information depend strongly on the specific message wording;

- a discussion of other factors influencing the effectiveness of messages. These include general network traffic conditions, and evidence of congestion visible to the driver. There is a natural tendency for drivers to prefer remaining on their current route. Related to this, compliance is also affected by whether a recommended route is aligned as the natural continuation of the route that the driver is already following. The main driver characteristics which have been observed to influence VMS compliance are their familiarity with the network and their previous experience of the reliability of VMS information. Drivers familiar with the network tend to prefer condition information rather than route recommendations; some studies have found that, for a given VMS guidance message, compliance by familiar drivers is around 10% lower than that by unfamiliar drivers; and

- a presentation of efforts to model the effect of VMS on route choice, focusing particularly on detailed models of the choice of exit link from individual intersections. The paper presents several estimation results for various multinomial logit model specifications of exit arm choice. These choice models are suitable for inclusion in traffic assignment model systems that allow en route diversions in response to real-time information.

Bovy, P. H. L., and van der Zijpp, N. J. (1999). "The Close Connection Between Dynamic Traffic Management and Driver Information Systems." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 355-370.

The authors discuss the interactions between traffic management and traffic information in the context of real-time dynamic traffic forecasting models. They argue that in many cases the traffic information provided to drivers should be based on future rather than prevailing conditions. However, because information can be based on forecasts of future conditions, but future conditions may themselves be affected by the information provided to drivers, the authors recognize a "chicken-and-egg" circularity which they analyze as a conceptual fixed point problem. The problem is expressed in terms of path splits (which the authors call routing fractions); these are influenced by the guidance messages received, and these messages are assumed to depend on the link volumes which are, in turn, affected by the path splits. The authors do not, however, provide a solution algorithm or carry out computational tests. The paper also mentions the difficulties caused by uncertainties in predicting future traffic conditions and driver responses to guidance messages.

The paper is a clear statement of many of the issues in predictive guidance, but does not go into details.

Boyce, D. E. (1988). "Route Guidance Systems for Improving Urban Travel and Location Choices." *Transportation Research A*, 22A(4), 275-281.

This 1988 paper is an early "big picture" discussion of advanced route guidance systems, including their design and potential impacts. It covers some of the prototype guidance systems developed up to that time, and considers the features that a more advanced system should include. These are:

- a communications system to enable two-way exchange of information between vehicles and traffic controllers;
- a traffic monitoring system, for collecting a variety of real-time data on traffic conditions and flows; and
- a traffic analysis and control system; the computer-based system would process real-time traffic data into travel time estimates and forecasts, and compute shortest time paths, possibly for alternative departure times.

Boyce identifies a number of transportation modeling and analysis issues that need to be addressed by an advanced route guidance system. He recognizes that a network model for guidance purposes must be dynamic rather than static. He proposed using quasi-dynamic models for this purpose since, at the time that he wrote, fully dynamic models were poorly understood and not capable of handling large problems. He recognized the importance of accounting for the effects of information, and particularly of imperfect information, on driver behavior. He emphasized the requirement in route guidance of distributing traffic over multiple paths in order to avoid over-concentration on individual paths and worsening of congestion. Finally, he discussed issues associated with system- vs. user-optimal guidance, and speculated on the opportunities in route guidance to achieve system-optimal flow patterns. These issues are still important, and some of the questions he asks have not yet received good answers.

He also recognizes the potential of route guidance systems to affect departure time and mode choice decisions, and to influence the selection of residential and job locations, through the provision of high-quality real-time information on the costs (including time) of different travel options. He discusses the integration of route guidance and traffic control systems, emphasizing opportunities for each to utilize information generated by the other; for example, information on flows and times could be utilized to optimize signal settings, while knowledge of signal settings is useful in generating guidance. Finally, Boyce sketches a possible phased implementation plan for an advanced guidance system.

Brand, D. (1995). “Criteria and Methods for Evaluating Intelligent Transportation System Plans and Operational Tests.” Transportation Research Record **1453**: 1-15.

Brand, D. (1998). “Applying Benefit/Cost Analysis to Identify and Measure the Benefits of Intelligent Transportation Systems.” Transportation Research Record **1651**: 23-29.

These papers discuss the evaluation of intelligent transportation systems using the methods of benefit-cost analysis (BCA). They argue that ITS plans and operational tests should be evaluated in a way that is sensitive to the differences between ITS and conventional transportation improvements. While the general principles of BCA – measure only impacts with economic value; avoid counting transfers; avoid double counting – continue to apply, the way in which ITS benefits and costs are quantified may be quite different from methods used in traditional improvement evaluation.

It is helpful to separate ITS supply- and demand-side effects. Commonly-stated ITS supply-side objectives, such as improvements in the efficiency of transportation operations, do not in themselves reflect economic value; it is rather the consequences of these improvements, in the form of safety, environmental and energy consumption improvements, that have economic value and should be counted.

Demand-side mobility goals are difficult to measure *a priori* because ITS enables travelers to make many activity and travel substitutions that were not possible before. In any case, improved mobility translates into increased productivity, so either one may be chosen for measurement, but not both. The papers suggest measuring ITS mobility benefits for personal travel, and productivity benefits for commercial travel.

The papers discuss with some care the evaluation of ITS mobility benefits. In the context of traditional investment evaluation, mobility benefits are directly tied to the reductions in the amount of time or travel over the network. ITS gives people and firms better information with which to make travel consumption decisions, and provides opportunities for eliminating scheduling slack that would otherwise be necessary to account for the uncertainties in travel time between activities. Therefore, the end of result of an ITS deployment may be *more* time and travel over the network, with this increase reflecting a net utility gain to the travelers via the other activities that improved travel information makes possible.

Two approaches are generally available to measure or infer traveler utility. Revealed preference methods observe the attributes of the actual choices that people make, and deduce from them the underlying utilities that the choices reflect. In the context of ITS, these methods are not always appropriate because the most readily accessible attributes of travel choices – travel time and cost – do not vary directly with the utility of the (possibly new) activities that generate travel.

Furthermore, cost attribute data is unreliable because ITS services are not yet traded in a market environment.

Stated preference survey methods are an alternative to revealed preference methods; they ask ITS users what they would prefer or how they would behave in various hypothetical situations. When carefully designed, administered and analyzed, stated preference surveys can illuminate key ITS attributes in terms of their impact on traveler utility, and can derived the implied willingness to pay for the corresponding attributes. These are direct measurements of ITS benefits to its users, and already include ITS effects on activity and travel substitutions, effects that would otherwise be very difficult to model.

Thus, the papers recommend the application of stated preference customer satisfaction methods to quantify the benefits of ITS to individual users. By appropriately scaling these results, the economic benefits of ITS at metropolitan, regional and national levels can be measured.

Casey, R., L. Labell, L. Moniz, J. Royal, M. Sheehan, T. Sheehan, A. Brown, M. Foy, M. Zirker, C. Schweiger, B. Marks, B. Kaplan and D. Parker (2000). Advanced Public Transportation Systems: The State of the Art, Update 2000, Volpe National Transportation Systems Center.

This report presents the results of an investigation of the use of advanced public transportation technologies in North America, focusing on applications in areas of fleet management, traveler information, electronic fare payment, transportation demand management and the intelligent vehicle initiative. (It is one in an on-going series of State of the Art reports).

Of particular interest here is the section on Traveler Information Systems in public transportation (Chapter 3 of the report). The report discusses pre-trip and multi-modal information systems; in-terminal and wayside information systems; and in-vehicle information systems. In each of these areas, it provides a summary of the types of information typically communicated to transit patrons, along with a high-level description of the technologies that are used for this purpose and the challenges to implementation. Finally, a number of recent operational examples of systems are described, including in some cases pictures or computer screen shots of the system as it presents itself to users.

Forms of pre-trip information discussed in the report include

- general service information (route, schedule and fare information by phoning a transit customer service center or from maps and schedules);
- itinerary planning information, where a patron requests an itinerary based on well-defined path choice criteria;
- real-time information generated by AVL-equipped vehicles, and presented on a map display or as the ETA of the next vehicle; and
- multi-modal information systems, which combine static and real-time information for a variety of modes and from a variety of sources.

In-terminal and wayside information systems provide information such as up-to-date schedules and vehicle arrival status reports. They may help in trip-rerouting, or may simply relieve passengers’ anxiety about when or whether the next vehicle will arrive. Technologies traditionally utilized for this purpose include video monitors and variable message signs; more recently, cell phones, alphanumeric pagers and handheld computers are being used as well.

In-vehicle transit information systems provide en route information to travelers. They can also help transit properties comply with the ADA, which requires announcing vehicle stops at all train stations and at key bus stops, relieving vehicle operators of this requirement. Such systems can also be helpful for riders who are unfamiliar with the vehicle's route, or when outside visibility is restricted due to crowding. Information can be provided visually (through in-vehicle alphanumeric displays similar to small-scale variable message signs) or via an audible bus public address system (information annunciators). Relatively few North American transit properties currently use either of these technologies; where they are used, annunciators tend to be more frequently installed than display systems.

Chatterjee, K., and Hounsell, N. (1999). "Modelling Driver Response to Variable Message Signs with RGCONTRAM." Selected Proceedings of the 8th World Conference on Transport Research, 597-610.

This paper describes methods that have been used to identify and model driver response to variable message signs and to incorporate this in RGCONTRAM, a dynamic traffic assignment model. The paper focuses on two applications of variable message signs: to inform drivers of incidents, and to indicate car park space availability.

The authors briefly review methods for assessing the network-level impacts of variable message signs, including before-and-after field studies and traffic assignment models incorporating a driver information component. They point out the limitations of field studies; these include:

- because VMS is frequently used in incident situations which are random and unique, it is difficult to predict what traffic conditions would have been in the absence of a VMS;
- VMS impacts on diversion rates are typically small and difficult to separate from the inherent variability of traffic;
- urban areas typically provide many diversion opportunities so it is difficult to determine the total diversions produced by a message; and
- results are specific to the particular location of the field test and may not be transferable.

The authors briefly discuss a number of traffic assignment models developed in the UK that incorporate information effects, and particularly driver response to VMS. Most of these have concentrated on modeling the network effects of VMS messages about incidents, although a limited amount has also been done modeling parking guidance and information (PGI) systems. Methods of modeling driver response to VMS include the use of fixed diversion routes, simple response logic and probabilistic models. A fixed diversion route is a predetermined alternative route which drivers are assumed to divert to when notified by a VMS of an incident. Simple response logic selects the diversion route based on tripmaker characteristics, traffic conditions and information, but is inherently deterministic. Probabilistic models account for uncertainties in modeling driver behavior, and specify the probability that a driver will divert to each of different possible diversion routes, again given driver characteristics, conditions and information.

The article next describes two efforts to incorporate driver response to VMS into RGCONTRAM, a dynamic network loading and traffic assignment model that allows drivers to change paths at en route locations (McDonald, Hounsell et al. 1995).

The first is a VMS system used for incident notification in London. To develop driver response models, a stated preference survey was conducted to provide background evidence on drivers' opinions about VMS. The surveys were distributed to drivers on two major London roads. They obtained information about trip and driver characteristics (including familiarity with the road network), then posed several hypothetical congestion scenarios, including response to observed congestion (but no VMS), and response if particular VMS messages were displayed. Survey responses were used to develop logistic regression models relating the diversion probability to driver, trip and message characteristics. Data on model variables and coefficients are not provided. Within RGCONTRAM, possible diversion routes are identified by computing shortest time paths based on higher than average link times between the VMS and the incident location. There does not appear to be any feedback mechanism in the model system to ensure consistency between the travel times used to compute the diversion probabilities, and those that result after drivers divert to alternative routes.

The second is a research project investigating the effectiveness of PGI systems. Times and costs associated with access to, egress from and maneuvers within parking facilities are represented by coding special links in a conventional transportation network model. The driver is assumed to make a joint choice of parking facility and route before departing from the origin, and this is only reconsidered if unexpected conditions (a PGI sign or a full car park) are encountered en route. Driver response data was obtained using a travel choice simulator (called PARKIT). Experimental subjects were asked to "drive" the simulator through a hypothetical network, and their route and parking location choices are noted. Different experiments vary parking cost, expected risk of having to wait to park, waiting time and PGI information. Again, details of the model specification and estimation results are not provided.

Chen, P. S.-T., and Mahmassani, H. S. (1991). "Reliability of Real-Time Information Systems for Route Choice Decisions in a Congested Traffic Network: Some Simulation Experiments." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 849-856.

From the abstract:

"This paper investigates the reliability of information on prevailing trip times on the links of a network as a basis for route choice decisions by individual drivers. It considers a type of information strategy where no attempt is made by some central controller or coordinating entity to predict what the travel times on each link would be by the time it is reached by a driver that is presently at a given location. A specially modified model combining traffic simulation and path assignment capabilities is used to analyze the reliability of the real-time information supplied to the drivers. This is accomplished by comparing the supplied travel times (at the link and path levels) to the actual trip times experienced in the network after the information has been given."

The investigation, in other words, analyzes the reliability of prevailing trip time information as compared to actual experienced times, in the context of a network with congestion and real-time information provision. The traffic simulations are carried out using an early form of the Dynasmart simulation-assignment model, including in particular the route switching model based on either deterministic minimum path choice or on a boundedly-rational indifference band.

Different runs varied the type of information provided (pre-trip, en route, both or none); the assumed route switching behavior rule; and the fraction of drivers assumed to receive real-time information (market penetration rate). The information reliability was analyzed in terms of whether the route recommended on the basis of prevailing times was actually the best in terms of experienced times and, if not, the magnitude of the time difference between the two. Reliability results were reported in terms of the fraction of total recommendations that proved to be incorrect, and the average difference in trip times on the best and the recommended routes, when the recommended route was not the best.

Although the results vary considerably depending on the particular combination of assumptions that is made, the overall conclusion is that basing messages on prevailing conditions may not be very reliable, especially at high market penetration rates.

Chen, P. S.-T., and Mahmassani, H. S. (1993). "Dynamic Interactive Simulator for Studying Commuter Behavior Under Real-Time Traffic Information Supply Strategies." *Transportation Research Record*, 1413, 12-21.

This paper describes a travel choice simulator developed at the University of Texas at Austin. It offers the capability for real-time interaction with and among multiple driver participants in a traffic network under ATIS message provision. The simulator allows several experimental subjects to "drive" through the network, interacting with other drivers and contributing to system evolution. It considers both network conditions as influenced by driver response to real-time traffic information, and driver behavior as influenced by real-time traffic information derived from network conditions. The core of the system is the Dynasmart mesoscopic traffic flow simulator and an ATIS message generator that displays messages consistent with the simulated network state. Decisions about departure time choice, route choice and route switching made by the experimental subjects are input to the simulator and so influence the network and the ATIS messages subsequently provided during a run. The simulator operates in real-time, i.e., the rate of passage of time during a simulation is the same as actual clock time; a single trip generally takes around 20 minutes.

In addition to studying users' responses to ATIS messages for a particular time period within a particular day, the simulator also allows the investigation of the day-to-day evolution of drivers' behavior as they acquire experience with the properties of network traffic conditions and the ATIS.

At the beginning of a run, each subject is provided with a "snapshot" of current travel times (possible future changes in travel times are not predicted) and, on the basis of that information and prior experience with the simulator, selects a departure time and path. These decisions are fed into the Dynasmart traffic simulator. Once departed, each subject's vehicle is moved along the selected path in accordance with the travel conditions prevailing on each link that it traverses. In addition to the vehicles "driven" by the experimental subjects, there are roughly 11,000 other vehicles on the network that are managed by Dynasmart and contribute to network traffic conditions. Interactions among all the vehicles determine the levels of congestion and travel times in the network. Dynasmart moves individual vehicles on a link at speeds determined from a macroscopic speed-density relationship (a modified Greenshield model). Vehicle movements from one link to another are subject to capacity constraints. Spillback with queue formation occurs when a downstream link is blocked.

When a vehicle arrives at a decision node and has the opportunity to switch routes, the driver is again provided with a snapshot of current travel times and asked to decide whether to remain on the current route or to switch to another. Vehicles managed by Dynasmart and with access to ATIS can apply either of two path selection and switching decision rules: a myopic rule that invariably selects the route with minimum remaining trip time to the destination, and a version of bounded rationality according to which a driver switches from the current path to the minimum time path only if the improvement in the remaining trip time exceeds some threshold (which may be expressed either in absolute terms or relative to the remaining trip time, and may vary across drivers).

At the end of the trip, the user is given feedback about his or her departure, arrival and trip times. The next day's trip then begins. The process continues until system convergence (not defined in the paper) is achieved or a predetermined number of iterations is exceeded.

The test network consisted of a simulated commuting corridor consisting of three parallel facilities. Traffic enters at a number of locations on the initial segments of each facility, and all traffic continues to a single common destination. There are four crossover locations at which a driver on any facility can divert to either of the alternative facilities. A path between a decision point and the destination is assumed to consist of the connecting link and an alternative facility; multiple facility switches downstream are not considered. Thus, at each such decision point, three possible paths are available to proceed to the destination.

The system can be run to test the effects of a number of factors including origin location (which determine the number of decision points encountered during a trip); percentage of managed vehicles assumed to have access to ATIS (i.e., the market penetration rate); time allowed for decision making by the experimental subjects; rate of update of ATIS messages; simulation speed (real-time or faster); and information display strategies.

Chen, P. S.-T., and Mahmassani, H. S. (1999). "Dynamics of Urban Commuter Behavior Under Real-Time Traffic Information." *SWUTC/99/472840-00066-1*, Center for Transportation Research, University of Texas, Austin.

This report is presents a behavioral research effort to examine the processes underlying commuter decisions on en-route diversions and day-to-day departure time and route choices as influenced by the provision of real-time traffic information.

This report presents a series of large-scale laboratory-like experiments in which real commuters interact with and among multiple participants in a traffic network in real-time under various information strategies through a dynamic travel simulator. The simulator and details of the experimental setup are described in (Chen and Mahmassani 1993). By actually simulating traffic conditions in response to the supplied commuter decisions, the simulator provides stimuli to the participants that are always consistent with physically realistic traffic behavior, and with their previous actions.

Four aspects of tripmaker behavior in response to real-time traffic information are investigated:

- compliance behavior of ATIS users. The experiments aim to investigate the association between switching decisions and compliance decisions, and to determine how the accuracy of provided information affects the level of compliance;

- ATIS user satisfaction. The experiments attempts to relate the number of switching decisions made per trip to information quality and schedule delay, and to detect any trends over time towards a traffic pattern in which no switches are desirable in recurrent traffic conditions;

- user tripmaking behavior under different ATIS strategies. The objective is to investigate how different possible information provision strategies affect commuter travel decisions. Strategies considered include provision of prescriptive vs. descriptive messages; and different levels of information quality; and

- dynamic switching models of ATIS users. This investigates the importance of prior experiences with ATIS in determining system credibility, and the ways in which message credibility and reliability influence pre-trip and en route behavior.

The data collected from these experiments formed the observational basis for the development and calibration of Poisson event count models of user compliance and satisfaction behavior, and of multinomial probit models of dynamic departure time and route switching decisions.

A number of general conclusions were drawn from the analysis and modeling exercises conducted with the experimental results.

Compliance behavior and satisfaction with ATIS were strongly related to various aspects of message accuracy. These included both the nature of the provided messages (e.g., based on predicted vs. prevailing traffic conditions; descriptive information vs. prescriptive recommendations) as well as observed discrepancies between ATIS messages and actual conditions in prior trip experiences (e.g., differences between reported and experienced times; encounters with unexpected congestion on prior links; schedule delays, particularly involving late arrivals).

The initial indifference band for pre-trip route adjustment was wider than that for en route path switching (i.e., travelers were generally more hesitant to switch routes before beginning a trip than during it).

Tolerance for schedule delay and the "width" of the indifference band could be related to the socio-economic characteristics of travelers. For example, older travelers tended to have greater schedule delay tolerance, and female travelers exhibited a wider indifference band for pre-trip departure time and route choice decisions, as well as for en route path switching decisions.

Prior trip experience also conditioned travelers' acceptance of unfavorable experiences with traffic or with ATIS messages. For example, travelers were more inclined to tolerate a high schedule delay if they had recently experienced a substantial increase in travel time as a result of a small adjustment in departure time.

Estimated variance-covariance terms in simultaneous models of departure time and pre-trip route choice were all significant, indicating the need to treat these decisions in a combined framework.

There was some evidence for a long-term trend towards reduced switching as user behavior and traffic conditions evolve over time in response to ATIS messages.

Cremer, M., Meissner, F., and Schrieber, S. (1993). "On Predictive Control Schemes in Dynamic Rerouting Strategies." Proceedings of the 12th International Symposium on the Theory of Traffic Flow and Transportation, 407-426.

The authors consider the problem of re-routing vehicles on a traffic network following an incident. They argue that effective re-routing strategies must be based on predicted traffic conditions, which a traffic network model is used to obtain. They sketch a basic rolling horizon control approach based on a traffic prediction model which, in each roll stage:

- is initialized with the prevailing traffic conditions and an estimate of future OD flows;
- undertakes an iterative computation of re-routing messages. The iterative computation consists of repeating the following steps until satisfactory measures of effectiveness are obtained:
  - selecting a set of guidance messages;
  - running a traffic prediction model over the guidance horizon, taking account of the selected guidance messages; and
  - calculating the measures of effectiveness of the guidance messages (based either on system- or on user-optimality);
- applies the messages when satisfactory measures of effectiveness are predicted; and then
- moves on to the next roll stage.

To illustrate their ideas, the authors develop and apply a dynamic traffic flow model based on Payne's macroscopic flow relationships. The model requires user input of a fixed rate of compliance with guidance re-routing messages.

They apply the model to a simple network on which an incident occurs and contrast the effectiveness of guidance based on prevailing and on predicted conditions. They show that the latter is more successful than the former both at reducing total network travel times as well as individual user times.

The authors also claim to identify certain situations in which user optimum guidance is impractical. In these cases, they seem either to be evaluating user-optimality based on a system-optimality criterion, or to be inaccurately computing a time-dependent user optimal flow pattern.

Dehoux, P., and Toint, P. L. (1991). "Some Comments on Dynamic Traffic Modeling in the Presence of Advanced Driver Information Systems." Advanced Telematics in Road Transport, Proceedings of the DRIVE Conference, 964-980.

This relatively early paper discusses some of the issues related to dynamic traffic modeling in the context of ATIS, with particular reference to the model system PACSIM.

The authors argue in favor of using a dynamic rather than a static traffic model with ATIS, and recognize that some generalization of the classical concepts of Wardropian equilibrium is called for in order to represent driver response to (possibly imperfect) information. They list a number of desirable features of a traffic model for use in this application:

- a flexible and standardized mechanism for representing user behavior; in fact they argue that behavioral theory should be an easily changeable *parameter* of a traffic model system. In PACSIM, they implemented a formal language for describing behavioral rules applied in route choice decision making;

- a behaviorally coherent traffic "metaphor", meaning that the traffic flow units represented in the model should be disaggregate enough to capture significant variations between different types of drivers and ATIS users. They argue in favor of use of packets, groups of vehicles or drivers with identical behavioral characteristics;

- an explicit time reference. This refers both to the need for dynamic models (i.e., of time-dependent processes) as well as to the various ways in which timing might be captured (e.g., event-based simulation, time slices, or something else);

- a flexible network representation, capturing drivers' formation of route alternatives into choice sets. The authors propose an approach in which the level of detail of network representation decreases with the distance from (potentially) each node in the network. The perceptual traffic network that drivers consider in making their route choices depends on their position in the network; and

- an explicit model for information flows. In parallel with the network of road infrastructure, the authors argue that the network of information collection, transmission and processing infrastructure should also be represented, including such details as the location of traffic monitoring and message dissemination equipment; the strategies used to process information from the network before subsequent redistribution to drivers; and the accessibility of different types of information to different classes of users.

Dudek, C. L., Weaver, G. D., Hatcher, D. R., and Richards, S. H. (1978). "Field Evaluation of Messages for Real-Time Diversion of Freeway Traffic for Special Events." *Transportation Research Record*, 682, 37-45.

Richards, S. H., Stockton, W. R., and Dudek, C. L. (1978). "Analysis of Driver Responses to Point Diversion for Special Events." *Transportation Research Record*, 682, 46-52.

These two articles report on research in the late 1970s into the effectiveness of variable message signs in diverting traffic that was going to special events at a large fair ground complex in Dallas from a main freeway to an arterial alternative route. A message dictionary consisting of 14 possible message sets had been created through human factors laboratory studies. These could be selected by human operators in real time. Some message sets included only prescriptive and navigational messages, while others included quantitative or qualitative information about delays and indications about delay avoidance possibilities.

The study procedure involved a comprehensive license-plate based origin-destination technique as well as separate mail-in questionnaires sent to people who had diverted and others who had not. The questionnaires attempted to identify basic driver and trip characteristics and determine the reasons for the choice.

In general, it was found that the VMSs did influence route diversion to the alternative route. The effectiveness of different messages and degree of diversion and depended to some extent on whether the event at the complex had a fixed starting time or not. For fixed time events, there was no discernible difference in effectiveness among the different messages. For events with starting times spread over a large time period (e.g., a fair), descriptive messages (traffic conditions or travel times) produced the highest diversion. Repetition of a message at two successive locations did not appear to increase the diversion rate.

Drivers who were less familiar with the routes were more likely to divert. Anticipated dissatisfaction with the alternative route was the most frequently cited reason for non-compliance, and driver lack of confidence in the messages was the least frequently cited reason. Reasons cited for not diverting were consistent between familiar and unfamiliar drivers. More than 14% of the sampled drivers said that they would have liked additional information on parking availability in the complex, and 9%-10% said that they would have like additional en route guidance, or guidance on the return route.

Duffell, J. R., and Kalombaris, A. (1998). "Empirical Studies of Car Driver Route Choice in Hertfordshire." *Traffic Engineering and Control*, 29(7 and 8), 398-408.

This study deals with the route choice behavior of car drivers during the morning peak period at four locations in the county of Hertfordshire, UK. At all of these locations, commuters traffic mixes with traffic from drivers taking children to school, or dropping children off at school on their way to work.

Two kinds of data are used for the research. The first one was traffic data collected in the field at these locations. The second one is a questionnaire survey that investigates the reasons for car driver route choice. The sample comprised of 255 completed questionnaires.

Four case studies are used to understand drivers' route choice behavior at the four locations. The routes available were the main route and the particular secondary route identified at each locations. The data is used to understand (i) driver behavior in normal and school half-term weeks; (ii) driver behavior given a left or right hand turn choice to get to the same point in a network without any advantage in time and distance by either route; (iii) route choice following the conversion of a signalized intersection to a double mini-roundabout; (iv) route patterns following the introduction of new major links into two existing highway network; (v) route choice through a network involving either two right hand turns across major road flows in one direction or two left hand turns from and into the same major road in the opposite direction; and (vi) driver behavior with respect to a right hand turn ban which was effective during the morning peak period.

The results of the observations indicated that travel time is the single most important criterion affecting driver route choice in networks where there is a viable alternative to the main route. The field observations also demonstrate that drivers are willing to incur some extra travel distance to find the quickest route, provided the extra distance is not excessive or the alternative tortuous. If the traffic queues are moving, drivers may forgo a perceived and possible time saving in favor of the predictability of the main route time. The empirical observations have confirmed the findings of the questionnaire survey.

A multi-linear regression model was estimated expressing the percent of drivers diverting from the main route as a function of travel time ratio of the main route and the secondary route, the distance ratio of the main route and the secondary route, the speed ratio of the main route and the secondary route, and the travel time difference of the main route and the secondary route.

Emmerink, R. H. M., Nijkamp, P., Rietveld, P., and Axhausen, K. W. (1994). "The Economics of Motorist Information Systems Revisited." *Transport Reviews*, 14(4), 363-388.

This paper illustrates some of the economic issues associated with the implementation of ATIS under different scenarios.

This paper assumes a properly working ATIS, i.e. an information system that reduces the travel time of equipped drivers, and makes them better off than non-equipped ones. Under this assumption, and the assumption of Wardrop's user equilibrium at full market penetration, the study shows that the marginal benefit of ATIS to equipped drivers is a decreasing function of the level of market penetration. Moreover, they are zero at full market penetration. Therefore, a marginal equipped driver adversely affects the already equipped ones. However, this marginal driver will have a positive influence on non-equipped drivers. Hence, it can be concluded that an ATIS is an economic good that produces both positive and negative externalities. Without correction, these externalities will cause market failures to take place. The size of these failures depends on the relative size and importance of the externalities.

By avoiding searching for the location of the destination, an ATIS may produce a decrease in distance traveled. However, because of improved information, ATIS may induce more travel demand. Road network traffic increases, but the new equilibrium travel time is below the one before implementation. The market potential of these new technologies is strongly dependent on the value-of-time curve, the information benefits to equipped drivers curve and the cost structure of the ATIS. The market potential increases when the road network is strongly volatile, i.e. a network with non-recurrent congestion. Then, the information benefits to equipped drivers might still be significantly positive at full market penetration.

If an ATIS can be characterized by decreasing average costs to scale – which seems a reasonable assumption given the large initial investment needed – a welfare-maximizing marginal cost pricing strategy would lead to a deficit for the company operating the system.

The paper did not address the other potential implications of ATIS, such as stress and anxiety reduction, decrease in pollution, increase in safety, etc.

An ATIS is only one of the available tools to tackle the congestion problem. As a stand alone system, the impact might be small in practice. However, combined with a congestion pricing strategy, transportation planners have a strong tool to influence traffic flows in road networks.

Emmerink, R. M., Axhausen, K. W., Nijkamp, P., and Rietveld, P. (1995). "The Potential of Information Provision in a Simulated Road Transport Network with Non-Recurrent Congestion." *Transportation Research C*, 3(5), 293-309.

This study analyzes the network-level effects of ATIS in the presence of incidents. It simulates the individual-level decision-making of a population of drivers, and aggregates the decisions to determine network-level traffic conditions. Driver behavior is modeled using a principle of bounded rationality. In such a model, drivers are seeking a satisfactory outcome, rather than a utility maximizing one: they will change a behavior if the change results in a significant improvement in their utility, but not otherwise. Simulation experiments are performed in the network with non-recurrent congestion focusing on the following issues:

- the influence of the level of market penetration on the network wide performance;
- the additional benefits to equipped drivers; and
- the quality of the information in relation to drivers' behavior and network wide performance.

Impacts of ATIS are assessed solely in terms of its implications for travel time reduction.

Some sources affecting the quality of information are: level of precision and reliability of the traffic measurement technique; reliability of the broadcasting channel; delay in transmission of the information; updating frequency of the information; and the format in which information is provided. The simulation experiments in this study only deal with information inaccuracies caused by a discrete updating frequency. Three updating times of 1, 5 and 10 minutes are considered, while traffic conditions change continuously. In the simulation model, drivers travel daily from the same origin to the same destination, using past trip experience in making route choice decisions. It is assumed that departure times are fixed and that all drivers depart during the first hour of simulation. The road network used for the simulation consists of one origin and one destination, connected by 25 different routes and 9 decision points. Each simulation run covers 200 days and is repeated five times to account for stochastic effects.

Two driver behavior models are used: a pre-trip information updating model and en-route switching model. Equipped drivers are provided with en route information on expected remaining travel time. Random incidents are generated in the simulation at the rate of one per day. Incident duration is 15 minutes.

The performance indicators used in this analysis are the average travel time for drivers with and without information and the network wide travel time. The results indicate that the variance in daily network-wide travel time decreases as the level of market penetration increases. The network-wide travel time decreases with increases in the market penetration rate. Based on the above findings, it is concluded that boundedly rational drivers without information access in a network with non-recurrent congestion are unable to choose routes leading to an efficient use of the road network in terms of total travel time. It is also found that the additional benefit to equipped drivers decreases quickly as the level of market penetration increases. Non-equipped drivers are also affected by the presence of equipped drivers, and their benefits depend upon the level of market penetration as well.

A decrease in the updating frequency has an adverse effect on network-wide performance. The size of this negative effect depends on the market penetration rate (i.e. the number of drivers making their tripmaking decisions based on out-of-date information). At full market penetration, impact of a low updating frequency on network-level travel time is 12%. However, the network-wide situation at full market penetration is still considerably better than without information.

A number of general conclusions were obtained from analysis of the simulation results:

- if the level of market penetration is relatively low, then the quality of the information in terms of travel time is not crucial;

- if the level of market penetration is relatively high, then the switching propensity should be relatively low; and

- if the quality of information in terms of updating frequency is relatively low, then the switching propensity should be relatively low.

Emmerink, R., Nijkamp, P., Rietveld, P., and Van Ommeren, J. N. (1996). "Variable Message Signs and Radio Traffic Information: An Integrated Empirical Analysis of Drivers' Route Choice Behavior." *Transportation Research A*, 30(2), 135-153.

This article presents an analysis of the impact of radio traffic reports and VMS messages on route choice behavior, based on a survey of road users in Amsterdam. Radio traffic reports are broadcast roughly every 20 minutes and provide information on traffic queue lengths in heavily congested portions of the road network. VMS (called RIA in Amsterdam) also provide information on traffic queue lengths and on lane or tunnel closures, but are updated, using data from an extensive system of loop detectors, every 4 seconds. Furthermore, RIA signs are generally installed at key network decision points, so that information reaches drivers just before they need to make a decision.

Mail-back questionnaires regarding socio-economic characteristics, travel characteristics, use of radio traffic reports and use of RIA messages were distributed to drivers at filling stations located near one of the RIA signs.

A variety of analyses were performed on the survey data.

Turning first to the use of radio traffic reports, the authors specified and estimated an ordered probit model of frequency of listening to traffic radio: never, regularly or frequently. All variables collected in the questionnaire were considered as possible independent variables. It was found that a driver is more likely to listen to radio traffic information if the length of trip is long, there is more than one route available, the driver is on a business trip, is less than 45 years old and is male.

An ordered probit model of the frequency with which route choice decisions are influenced by radio traffic reports was also estimated. Dependent categories were "route choice has never been influenced", "route choice has infrequently been influenced" and "route choice has frequently been influenced" by radio traffic information. The model was estimated using observations where more than one route was available and where radio traffic was listened to regularly or frequently. Broadly speaking, the variables and their degree of influence were similar to those found in the radio traffic use study, with some differences: for example, a short trip distance was more likely to result in a radio-based route choice effect. Arrival time flexibility did not have a significant impact on radio traffic report influence.

Turning now to the influence of RIA signs on route choice, an ordered probit model was again estimated. Dependent variable categories were similar to those used in the analysis of radio traffic report influences, and observations were screened on the basis of exposure to an RIA sign and relevance of the sign's messages to the particular trip being made. It was found that drivers who more frequently passed an RIA sign were more likely to change their route. Drivers with flexible arrival times were less likely to be influenced by the RIA messages. Commuters were less likely to be influenced by an RIA than business travelers.

The authors conducted an analysis of driver satisfaction with RIA messages (although they note that, in the absence of post-trip feedback, it is difficult to judge whether one particular route was better than another). Drivers are more likely to be dissatisfied when the RIA message directs them off the motorway; however those directed to alternative routes not much longer (in terms of distance) than the usual one are relatively satisfied.

Next, the authors consider possible synergies between radio traffic reports and RIA messages; it is plausible that drivers who receive similar traffic messages from different sources will lend additional credence to them, and conversely. To this end, the authors specified and estimated a bivariate ordered probit model which allows for arbitrary (positive or negative) correlation in the error terms of the underlying response models. The dependent variable categories (relating to frequency of influence by radio or by RIA) are the same as those described above. Results of the bivariate estimation were very similar to those for two separate univariate models; however, the correlation coefficient of the two error terms was very high and equal to 0.5. This suggests that there is a latent variable (propensity to use traffic information) which is influencing the use of both the RIA signs and radio traffic reports.

Finally, a model of willingness to pay for in-vehicle traffic information was estimated from SP questionnaire responses. Again, a bivariate ordered probit model form was used. Dependent categories were frequency of listening to radio traffic reports, and willingness to pay for an in-vehicle device (expressed in ranges of monetary amounts per year). It was found that the estimated correlation coefficient of the bivariate normal error term is significantly positive, although smaller than 0.5. This implies that there is a small positive correlation between listening to radio traffic and willingness to pay for in-vehicle information, and again suggests the presence of a latent propensity to use traffic information that influences both behaviors. Drivers who report good experiences with RIA messages in the past tended to have positive willingness to pay. People traveling on business trips have higher willingness to pay. However, 50% of the drivers in the survey stated that they would not be willing to pay to receive in-vehicle information, although this response could reflect a strategic bias. In an attempt to eliminate this bias, the bivariate ordered probit model was re-estimated using only drivers who had indicated a willingness to pay some positive amount for traffic information. Unexpectedly, this reduced the error term correlation to insignificant levels. Thus, the question of a latent propensity to use information requires further research.

Engelson, L. "Self-fulfilling and Recursive Forecasts---An Analytical Perspective for Driver Information Systems." *Proceedings of the 8th IATBR Meeting*, Austin, Texas.

Engelson presents a rather general analysis of predictive information provision in situations where users' responses to the predictions are likely to affect the future being predicted; he used anticipatory route guidance as an example of such a situation.

Key to Engelson's analysis are the notions of *self-fulfilling* and *recursive* forecasts. "A self-fulfilling forecast is defined by the following property: if the message containing the result of the forecast is reported to the drivers before they make their route choices, then the expected value of travel time for each driver and each route will equal the value in the message." In other words, a travel time forecast is said to be self-fulfilling if, for each route and driver, the mean travel time that actually results on the network after the forecast is disseminated is what was stated in the forecast.

In contrast to this, the notion of a recursive forecast is model-based: it is only defined in terms of the models that are used to perform forecasts. "…a model of users' behavior and a model of service response {are needed}. The first model uses values of performance indicators which the agent includes in the message as input. The result of the model is a description of users' behavior, that is, the number of users choosing each action. The second model uses the result from the first model to estimate performance indicators, or to predict the service response….{A} recursive forecast is defined as a set of values which equates input of the first model with output of the second."

Engelson carries out his analysis in the context of static network equilibrium models. His performance indicators are just static path times and his user behavior model is essentially a path choice model that predicts the static path flows. Similarly, his service response model is a static network loading model. He states clearly that finding a recursive forecast amounts to finding a fixed point of a composite map obtained by combining the two models.

Although the analysis is couched in terms of the static network equilibrium problem, Engelson recognizes the generalization of his problem to dynamic networks; however, the paper does not analyze this generalization.

French, R. L. "In-Vehicle Route Guidance in the United States: 1910--1985." *2nd International Conference on Road Traffic Control*, 6-9.

In this article, French provides a brief and interesting survey of early route guidance systems, up to the period just prior to the beginning of civilian use of GPS.

Very early technological innovations include the odometer, the differential odometer and the magnetic compass. The odometer is first described by Hero of Alexandria and co-workers (ca. 200 BC); one model recorded distance by dropping stones into a receptacle after gears attached to the wheel axle had completed a certain number of rotations.

The differential odometer, invented by the Chinese *ca*. 200 AD, measures the difference in distances traveled by the left and right wheels of a vehicle and feeds this difference back to a direction indicator so as to keep the indicator pointing in a constant direction. (This invention considerably predates the discovery of the magnetic compass.) The device was reportedly used for wayfinding on long land journeys, although its practical accuracy for this purpose has been called into question.

The magnetic compass was described in Chinese literature in the 11th century, about one century earlier than its first mention in European writings. There is no known record of use of the compass for vehicle navigation prior to the invention of the automobile, probably because the construction (a magnetized needle floating in a liquid) would not have withstood the typically rough conditions of land travel.

Before the widespread use of automobiles, most trips were confined to a relatively local area. Routes were learned by experience and there was minimal need for direction signing. Automobiles enabled people to routinely travel beyond their area of familiarity, and the lack of signage then became a problem. A number of inventions were developed to address this need. They generally involved in-vehicle cylindrical or disc-shaped devices which were advanced at a rate that was synchronized with wheel rotations. The cylinders or discs had wayfinding information printed on them. When initialized with a trip starting location, information about the options at each decision point would be displayed prior to arriving there. Some versions also included static travel information such as road conditions, railroad crossings and speed traps.

Fujii, S., and Kitamura, R. "Anticipated Travel Time, Information Acquisition and Actual Experience: The Case of Hanshin Expressway Route Closure." *Transportation Research Board 79th Annual Meeting*.

Travel time is one of the most fundamental and important determinants of travel behavior. However, travelers use subjective judgment to calculate the travel time, i.e. anticipated travel time, on which their travel decisions are based. Objective travel time may serve as a proxy variable for anticipated travel time if and only if the difference between them is small and non-systematic. For a better understanding of the cognitive process of perception and prediction of travel times, it is important to understand how a driver forms an anticipated travel time when he faces a traffic condition he has never experienced in the past. This is because the anticipated travel time of a route would not change substantially once the driver establishes it well by repeated driving experience, while the anticipated travel time under unfamiliar traffic condition can be expected to be influenced substantially by information acquired by the driver. In addition, the initial driving experience may substantially influence the anticipated travel time formed under unfamiliar traffic condition. This study attempts to understand the formation of an anticipated travel time through initial driving experience and information acquisition.

A conceptual model of anticipated travel time formation was proposed in this study. It is assumed that an anticipated travel time affects anticipated travel times held in the future. This is labeled state dependence. The model is based on two hypotheses – 1) *Information Dominance Hypothesis*: information effects become larger as the driver acquires more information on travel time, and dominate state-dependence effects, 2) *Experience Dominance Hypothesis*: the influences of generic information on the anticipated travel time are weaker with actual driving experience than without it. In the model, the information effect and state-dependence effect are both posited, and the influences of information acquisition and driving experience on these effects are also postulated, representing the two hypotheses. The model is formulated as a structural equations model and estimated using the maximum likelihood procedure.

The data used in this study were collected in a survey in the Osaka Metropolitan Area to investigate commuting drivers' adaptive behaviors during the closure of a segment of the freeway system in the area for maintenance purposes. A freeway closure forces its regular users to change their driving habits and affects traffic conditions throughout the area. Consequently, drivers must acquire information on traffic conditions during the highway closure in order to be able to anticipate their travel times. The survey collected information on commuting travel mode, route, actual travel time, anticipated travel time and acquisition of information each day during the highway closure. Using this dataset, this study analyzed the impact of acquired information about traffic condition on anticipated travel time.

The statistical results of this study, despite the small sample size, lend empirical support to the Information Dominance Hypothesis, which holds that with increased information on traffic conditions, drivers predict travel times more precisely with less reliance on the anticipated travel times than they had in the past. However, the results indicate that word-of-mouth information has effects that are opposite to those implied by the Information Dominance Hypothesis, i.e. state dependence is strengthened and information effect is weakened. When anticipating travel time, a driver without any information or driving experience cannot help but resort to past anticipated travel times, which would obviously be different from actual travel time. With such poorly informed drivers, network flows may converge to a “deluded equilibrium” which could be very inefficient.

One possible strategy to break out of such a deluded equilibrium is to provide accurate information on traffic conditions. The Information Dominance Hypothesis is a necessary condition for this information provision strategy to work. However, the Experience Dominance Hypothesis implies that it may not be easy to break out of deluded equilibrium by providing travel time information. This is because the driver has been deluded by his actual driving experience and the hypothesis implies that actual experience diminishes the influences of acquired information in anticipating travel time.

Fujii, S., and Kitamura, R. "Framing Uncertain Travel Times: A Re-examination of Departure Time Choice." *Transportation Research Board 80th Annual Meeting*.

This study proposes a model of drivers commuting departure time choice, hypothesizing a cognitive task and a mental representation of uncertain travel times. It departs from the paradigm of expected utility theory, but refers to accumulated scientific findings of human decision making. Furthermore, by using departure time choice data, the study shows the presence of decisional phenomena, which can hardly be explained by expected utility theory, but are explained well by the proposed model. The motivation for this study is derived from the belief that expected utility theory is incapable of representing cognitive processes underlying observed travel behavior. Depiction of travel behavior under uncertainty requires adopting cognitive models, rather than probability theory, to capture the mental representation of uncertainty.

Motivated by imprecise probability theory, this study hypothesizes that an individual driver perceives uncertain travel time as an interval: Travel time will never exceed AT_{max} and will never be shorter than AT_{min}, where AT_{max} and AT_{min} refer to the largest and smallest anticipated travel time. This research hypothesizes that a commuting driver frames a departure time choice problem in terms of the dichotomy of being in time and being late. The following two reference time points are crucial for managing the risk of being late for the required arrival time, T_{fix}: $RP_{early}=T_{fix}-AT_{max}$ and $RP_{late}=T_{fix}-AT_{min}$. These two reference points divide the time for departure into the following three periods: Safe period ($-\infty$, RP_{early}), Risky period (RP_{early}, RP_{late}) and Failed period (RP_{late}, $+\infty$). In this study, a driver is hypothesized to choose one from among the set of two reference points and three time periods, giving five departure time alternatives.

Data used for this study were collected in a survey of expressway commuters in Osaka, Japan in 1998. The data include the respondent's personal attributes (age, sex and driving frequency), AT_{max}, AT_{min}, T_{fix} and departure time denoted by T_{dep}.

The proposed model hypothesizes that RP_{early} and RP_{late} are alternatives for departure time choice, which drivers subjectively construct. In this sense, they are singular points, and the model implies large number of commuters would depart at these two time points. The results support the hypothesis of the decision frame based on the maximum and minimum anticipated travel time and required travel time and contradict a utility based model.

Each alternative is hypothesized to correspond to strategy for managing the risk of being late. Four conjectures regarding the risk attitude are developed. (i) Commuters are expected to be risk averse. (ii) The subjective importance of required arrival time may be different across commuters. (iii) In the presence of flexible work arrival opportunity, the importance of required arrival time will be smaller. (iv) If the subjective importance of required arrival time is small, a commuter may not clearly differentiate the five hypothesized alternatives. A multinomial logit analysis with 286 respondents (with no missing variables) is performed to validate the four conjectures. The results, by and large, conform to the hypotheses of the conjectures.

Gillen, D., and Haynes, M. (2000). "Measuring the Aggregate Productivity Benefits from ITS Applications: The California Experience.", California PATH Program, Institute for Transportation Studies, University of California, Berkeley.

From the Executive summary:

“ITS applications, while encompassing a broad array of transportation strategies, specifically can be described as the use of advanced technologies in electronics and information to improve transportation system performance with regard to vehicles, highways, and transit systems.

“Because investment in ITS technologies will clearly have widely differing impacts, there is an inherent uncertainty in predicting the impacts of a particular ITS strategy in a given location. If we can better understand to what extent ITS strategies provide benefits to the economic output of a county or region, then decisions to invest in ITS in the future will be better informed. This report uses measures of productivity to assess the impacts that ITS applications have had in California counties.

“There have been numerous studies that look at the role that public capital investment has in affecting productivity and economic output. Recent literature has produced widely varying results, and the issue remains unsettled. To further delve into the relationship between public capital and economic output, this research addresses ITS technologies as a component of public capital in the transportation sector. It is important to note that ITS is a very particular type of public capital, broken down into several categories, each with its own specific characteristics.

“Traditionally, the impacts of ITS have been studied using purely technical models that measure the effects of ITS on speeds, time savings and costs. While this sort of analysis is not incorrect, it may be incomplete. What is not addressed is how and whether ITS investments make producers and consumers better off. To study this, two distinct but related economic models were developed to see how ITS fits into the California economy as a whole. The first model is a production function, and the second a productivity model that calculates Total Factor Productivity (TFP).

“To study the impacts of ITS on productivity and economic output, a database was constructed for the years 1969-1997. Data was collected for California counties on various economic and transportation statistics as well as levels of ITS implementation in each county. Variables included in this database were consequently used in the two models that were developed to analyze productivity and ITS applications. The two types of ITS applications for which data was collected were ramp meters and changeable message signs.

“The results of the production function analysis provide some new results for the public capital literature and for policymakers debating the issue of whether and how much to invest in public capital and particularly ITS. This model is the first attempt to empirically measure the impact of ITS. Previous work has looked at ITS on a project basis or drawn conclusions from simulation results. The results show that highway capital provides local areas (measured by counties) with a competitive advantage creating output gains. Previous research found that the gains were offset by losses in adjacent counties. The net impact was to redistribute economic activity. Our results differ since not all of the gains are obtained from adjacent areas. There is a net positive benefit. This is important for any highway project evaluation since there are benefits that should be included in any benefit cost evaluation.

“The impact of ITS applications has not been assessed in an economic model before. This research provides the first results to show ITS applications have a positive impact on economic growth by providing local areas with a competitive advantage. ITS creates economic gains. These gains do not appear to result from shifting economic activity from other jurisdictions. This result, however, needs further investigation.

“The second modeling effort was to develop measures of TFP. This productivity measure takes account of the aggregate growth in outputs as well as inputs. New technology affects the economy in several different ways. It can allow us to do old things in new ways and to do new things. Technology is an enabler and it must be combined with personal and industrial strategies to yield new experiences, new products and services to add to the economic and social welfare of California. This research has really focused on the doing old things in new ways, lower costs and improved productivity. To this end our estimates show ITS adds benefits that should be counted in any project evaluation. The benefits are in the form of improvements in productivity. This leads to cost reductions in the delivery of gross county product. This answers a question which arose from our estimates of the production function, if ITS increases output, how does this happen? What we do not yet know is where, in what industries the impacts occur.

“This research provides the first evidence of whether and how ITS contributes to economic growth and productivity – an objective established by the California Transportation Plan and ITS in particular. The next set of questions includes, what industries are most affected by ITS applications? Does it matter how many ITS applications are present, in other words, are there diminishing returns to similar ITS projects? Finally, does it matter how ITS projects are combined? This later question also arose out of our research on production functions as well, and will be a central part of the subsequent research agenda.”

Giuliano, G., Golob, J., Moore II, J. E., and O'Brien, T. "Advanced Technology and Integrated Public Transit: The San Gabriel Valley Smart Shuttle Field Operational Test." *Transportation Research Board 80th Annual Meeting*.

This paper presents results from an evaluation of a new technology Field Operational Test (FOT), the San Gabriel Valley Smart Shuttle (SGVSS), which attempted to integrate services of three local municipal operators and a regional fixed route transit operator. The purpose of the evaluation was to examine technical performance, user response, and institutional issues associated with development and deployment of the integrated system. The system was never fully deployed. While technical problems were serious and extensive, the outcomes of this FOT were primarily a function of institutional and organizational constraints. Institutional issues have been underscored by recent evaluations of transit technology deployments; however, multi-agency technology deployments raise concerns. The assessment in the paper is based on comprehensive and detailed monitoring of the FOT from its inception to its conclusion, a period of over three years. The research team conducted repeated in-depth interviews with all project participants. Each stage of the FOT was documented, and representatives of the research team attended all project meetings. Field visits were conducted at critical points of planning and deployment, and extensive observations were conducted during system installation and other critical periods of the FOT.

The analysis of FOT outcomes was presented in two parts in the paper. The first part provides explanations for observed outcomes, and the second part discusses lessons learned. The failure to achieve a functioning level of technical integration, or any type of service integration, and the abandonment of the SGVSS system at the end of the FOT is explained by six major factors: 1) relocation and recasting of the FOT, 2) time and budget constraints, 3) lack of commitment to or interest in system integration by project participants, 4) lack of clear goals and objectives, 5) software technical problems, and 6) weak project management.

The purpose of an FOT is to determine whether the given technology application is appropriate for large-scale application. Inherent in the test is a consideration of institutional context. There is no such thing as an FOT failure; there is much to be learned from tests that did not work as anticipated. While this FOT did not accomplish system integration, the paper mentions the following lessons that were learned for future advanced technology applications:

- Goals and objectives should be clear, appropriate, understood by all parties, and agreed upon by all parties, especially those charged with carrying out the FOT.

- Institutional arrangements should be formal, clearly specified, and should allocate responsibility and risk appropriately.

- Any FOT should pass a basic test for reasonableness before it is allowed to go forward.
- The technology should fit with the problem being solved.
- Delays are inevitable in FOTs and should be built into the schedule.
- New technology tests should be as simple and incremental as possible.
- Basic technical knowledge and computer literacy of participants can not be assumed.

Green, P., Sarafin, C., Williams, M., and Paelke, G. (1991). "What Functions and Features Should Be in Driver Information Systems of the Year 2000." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 483-498.

This paper, published in 1991, describes the potential capabilities of year 2000 driver information systems, and proposes a method for selecting among them.

It considers driver information system functions related to navigation, vehicle monitoring, traffic information, hazard warning, communications, motorist services, in-car reception of traffic signs and signals, office functions and entertainment. For each of these, possible system features were identified. In the area of traffic information, for example, system features included receipt of information on congestion, construction activities, freeway management, parking, traffic rules, vehicle access restrictions and weather. Features considered for the navigation function mostly related to way-finding (static route guidance), although there was some recognition of the possibility of providing guidance advice based on real-time traffic conditions.

Each feature was scored with respect to its effect on accidents; its impact on traffic operations; and its correspondence with driver needs. Many of these clearly had to be estimated. In the particular area of traffic operations impacts, the authors created an evaluation scheme derived from the literature on traffic congestion and commuting. Classes for improved traffic operations included impacts on mode choice, on route choice, and on traffic flow conditions. Driver needs and wants were derived from focus group studies, and the correspondence of features with these were determined for a number of typical driving scenarios. Scores were assigned by the authors (human factors specialists) using a five-point scale, not considering the possible effects of different levels of market penetration.

Weights were assigned to the feature scores across different evaluation criteria and the features were ranked. From this, five functions and a subset of their features were selected for further design and evaluation. The functions included road hazard warning, navigation, traffic information and vehicle monitoring. The features selected in the traffic information function were information on congestion, on construction activities and on weather conditions.

Among the entire set of features considered for possible inclusion in a driver information system, automatic crash notification was ranked highest, in-car reception of traffic signs and signals came next, and provision of information on congestion was ranked third.

Hall, R. W. (1993). “Non-Recurrent Congestion: How Big Is the Problem? Are Traveler Information Systems the Solution?” Transportation Research C **1**(1): 89-103.

Hall, R. W. (1996). “Route Choice and Advanced Traveler Information Systems on a Capacitated and Dynamic Network.” Transportation Research C **4**(5): 289-306.

These two papers by Randolph Hall analyze various aspects of ATIS system benefits, sometimes challenging conventional views.

In (Hall 1993), he questions whether the commonly-assumed effectiveness of ATIS in alleviating non-recurrent congestion (e.g., incidents) is overstated. He introduces the concept of “effective capacity”, which is the expected capacity of a roadway, over time, after allowing for the capacity-reducing impacts of incidents. Based on a series of simulation experiments, he shows that the effect of completely eliminating incident delays is an increase in effective capacity between 2% and 9% for a one- to five-mile bottleneck; this is considerably less than the increase in capacity obtained by adding one lane to a four-lane facility, for example. He also points out that any increase in effective capacity brought about by improved travel information will likely induce additional travel, thus reducing the benefits of the capacity increase as felt by drivers already on the road. (This argument is similar to that made regarding capacity addition through new construction.)

In (Hall 1996), he makes a number of points regarding ATIS benefits and impacts analysis. He reviews a number of simulation studies of ATIS network-level travel time reduction benefits as a function of the number of vehicles equipped to receive real-time ATIS messages (the “market penetration rate”). A number of these studies have found an “inverse U” shaped relationship, with maximum benefits occurring at market penetration rates of 20—30 percent. Some have found negative travel time reduction benefits at high rates.

Using a simple analytical queuing model, he shows that for some network structures such effects cannot occur. He speculates that the earlier results may be due to use of instantaneous rather than experienced travel times in the models applied by their authors; this would lead travelers towards dis-equilibrium behaviors and produce disbenefits. He argues that, in any case, the question of optimal market penetration rate is moot, since it should be determined through market forces and not enforced by policy fiat.

The paper also highlights the importance of developing accurate models of traveler response to information for generating guidance and predicting its network-level impacts. Finally, it argues strongly against attempting to manipulate ATIS messages (restricting or misrepresenting information) in an attempt to manipulate driver behavior.

Han, B., Algers, S., and Engelson, L. "Accommodating Drivers' Taste Variation and Repeated Choice Correlation in Route Choice Modeling by Using the Mixed Logit Model." *Transportation Research Board 80th Annual Meeting*.

In studies of individual route choice behavior, it is important to capture the heterogeneity in drivers' tastes. Taste variations across individuals result in differences in their responses to alternative attributes and in differences in their preference to various choices. Another important aspect to capture is the correlation between repeated choices by an individual over time; this needs to be incorporated when modeling drivers' learning process or using data from repeated surveys in model estimation.

This paper uses the mixed logit model to incorporate the effects of these factors in a model of route choice. In the mixed logit formulation, an additional term is included in the individual utility specification compared to the standard logit model. This additional term attempts to capture the heteroscedasticity among individuals and to allow the correlation over alternatives and time. Because of the non-closed form of the choice probabilities, the log-likelihood function for mixed logit model cannot be evaluated analytically. Simulation techniques are used to approximate the choice probabilities.

The paper tests the robustness of mixed logit model estimates, and the effects of different assumptions regarding the random term probability distribution. Out of many factors that can influence drivers' route choice, of particular interest in this study is to analyze the impacts of information-related factors in an incident situation.

The empirical data used in model calibration was collected by the Swedish Transport Research Institute. The entire survey procedure included focus group discussions, pilot surveys and mail surveys. Of particular interest in the survey was the impact of information related factors on route choices. Stated preference data was used.

Tests showed that model results were robust when the choice probabilities were simulated with 500 draws. (This finding cannot be generalized to other cases.) Tests were made of different error distributions (normal, uniform and log-normal) and model specifications. The mixed logit model with a log-normal error distribution could not be estimated due to computational difficulties. A logit model with fixed coefficients was also tested; it differs from the standard logit model by incorporating correlation between repeated choices. Dramatic statistical improvements in the performance of the models were found by allowing the coefficients of observed variables to vary randomly across individuals. The change in the estimated parameters caused by using mixed logit model is also significant. The magnitudes of the parameters are generally larger in the mixed logit relative to the standard logit model. The results also show that if a person cannot be given an estimation of the extent of the delay, he/she will be more willing to stay on the regular route.

Hato, E., Taniguchi, M., and Sugie, Y. (1995). "Influence of Traffic Information on Drivers' Route Choice." Proceedings of the 7th World Conference on Transportation Research, Sidney, Australia, 27-40.

This research used stated preference investigations of drivers' reactions to VMS messages. The hypothetical situations evoked in the SP questions involved route switching decisions between a tolled expressway and a parallel free facility. Respondents chose an initial route, were provided with various items of information (some contextual and some in the form of hypothetical VMS messages), and then stated whether they would switch to the alternative route. The questions investigated the effect on switching propensity of variations in trip purpose, the originally-chosen route, traffic conditions on the originally chosen route, level of expressway tolls, the accuracy of travel time information provided in VMS messages, the overall trip time, and the length of queues reported in VMS messages. Ordered probit models were estimated from survey results.

The model results clearly showed that route choice was strongly influenced by the information received from the VMS messages. The original route choice (made without current information) had an inertia effect on route choice after information was provided. The degree of congestion encountered en route before receiving information also influenced route choice behavior after the information was received. Drivers on the expressway were reluctant to switch to the parallel route in response to messages, although drivers on the parallel route exhibited no such effect when messages recommended switching to the expressway. The value of information increased in proportion to drivers' experience on the routes for which the information was given. Low accuracy information had a negative effect on the perceived value of the information, particularly on commute trips, for which drivers are under time constraints and want highly accurate and reliable information.

Hato, E., Taniguchi, M., Sugie, Y., Kuwahara, M., and Morita, H. (1999). "Incorporating an Information Acquisition Process into a Route Choice Model with Multiple Information Sources." *Transportation Research C*, 7(2-3), 109-129.

This paper proposes a route choice model that takes into account the process in which drivers use traffic information in an ATIS environment with multiple sources of information. The validity of this model is verified using actual driver behavior data, and empirical findings concerning drivers' behavior in acquiring and referring to information available from multiple sources in the process of choosing a route is presented. The route choice model proposed here includes an information acquisition model and an information reference model as external variables in order to express the differences in individual drivers' reactions to the information provided.

Revealed Preference (RP) data on driver behavior were collected and were used in model validation. The data were gathered in a travel survey conducted on the Tokyo Metropolitan Expressway Network in which drivers can actually make use of traffic information from multiple sources (radio traffic reports, three types of electronic road signs) in choosing their route. The survey was conducted by using a mail-back questionnaire form that was distributed to drivers who were stopped at a service area on the outskirts of Tokyo. Drivers were asked to furnish information on their route choice and use of traffic information as they traveled into the city on the day of the survey. A license plate number matching survey was also conducted. The travel times of cars to which questionnaire forms were distributed was calculated on the basis of toll booth records showing license plate numbers. The results were used to establish a one-to-one correspondence between the information displayed on the road signs and the traffic conditions on the day of the survey and drivers' actual behavior.

A preliminary cross-section analysis was conducted to examine how drivers' information acquisition rate and information reference rate for each traffic information source would vary in relation to their socio-economic attributes and travel attributes. The information acquisition rate indicates the percentage of drivers who obtained traffic information from a particular source either by seeing or hearing the information. The information reference rate indicates the percentage of drivers who used the traffic information thus obtained in choosing their travel route.

A route choice model which considers the information acquisition and reference process was subsequently developed. The model contains trip variables, including route selection characteristics, travel purpose and actually observable traffic conditions en-route such as the degree of congestion, variables pertaining to the information such as its accuracy and extent to which it is displayed, and also latent psychological factors based on the personal attributes and experience of individual drivers. It is assumed that drivers are influenced by these variables and factors in the course of deciding whether to acquire and refer to traffic information in choosing their route.

An attempt was made to extract information processing capability and cognitive involvement as latent psychological factors that influence driver behavior with respect to the acquisition and use of traffic information. This is done by formulating a covariance structural equation model that employs a measurement equation and a structural equation by extracting these factors as latent variables. An information acquisition model and an information reference model were derived using the two latent psychological variables estimated. It is assumed that drivers' decision-making structure regarding the acquisition and referencing of traffic information can be represented as tree structure, with information acquisition at the upper level and information reference behavior at the lower level. In this case, drivers are influenced by the reference utility of each information source at the time of information acquisition. Drivers access information if they think that its reference utility is high and vice versa. Using the information acquisition and reference probabilities calculated, a route choice model of binary logit form is proposed that takes into account differences in drivers' reactions to the traffic information provided.

Estimation results from the information acquisition/reference model show that the route choice model, structured with information acquisition behavior as the upper layer and the information reference behavior as the lower layer, is valid. In the case of radio information and travel time information, it is seen that the two latent psychological factors of cognitive involvement and information processing capability were included as significant variables. Cognitive involvement shows positive and significant parameter values. It is thought that the tendency for drivers to access such traffic information sources becomes stronger in proportion to their positive attitude toward traffic information and desire to know the traffic conditions. Information processing capability also shows positive and significant parameter values. This suggests that drivers' propensity to access traffic information sources increases with an increasing ability to process such information.

Heathington, K. W., Worrall, R. D., and Hoff, G. C. (1971). "Attitudes and Behavior of Drivers Regarding Route Diversion." *Highway Research Record*, 363, 18-26.

This study was a part of an overall research program in information systems at the Expressway Surveillance Project of the Illinois Division of Highways directed toward planning, developing and evaluating a freeway driver information systems (FDIS). The paper proposes to determine potential driver response to such a system by evaluating driver attitudes toward diversion during the work trip. Diversion probabilities associated with different delay times, travel times, and diversion costs were evaluated for the respondents interviewed.

A structured questionnaire was used to measure the driver's attitude toward to diversion to avoid an unexpected delay during the work trip, and also to measure the attitude toward diversion to save overall travel time during the work trip. The driver was placed in a hypothetical situation and given traffic information about the conditions on the freeway but not on any alternate routes. For each specified unit of delay and saving in travel time, the driver was asked to indicate the frequency with which he would divert if a given diversion cost was incurred. The specified time units were 15, 10, 5 and 1 minute. The costs associated with each time interval were approximately $1.20, $3, $5 and $10 per hour.

The attitudes of the respondents indicated that they are more receptive to diversion to avoid a delay or to save travel time on the trip to work than on the trip home; they further indicated that they would divert more to avoid a delay than to save travel time. The respondents were not too concerned with minor delays or a 1 minute saving in travel time. There was no significant difference between the proportion of expressway and non-expressway users diverting to avoid a delay on the trip to work. When reporting on their current diversion behavior, the respondents indicated that they diverted more because of accidents than because of heavy congestion. Radio traffic reports had less impact on diversion than visual observations for those respondents diverting less than 50 percent of the time because of heavy congestion.

A further analysis was made of the diversion responses to determine whether there existed any relationship between frequency of diversion and other selected characteristics of the respondents. A factor analysis was made to define any variable that tended to load or group with responses for diversion. 20 responses were used for the factor analysis. The factor scores obtained from the factor analysis were very low. There seemed to be no definite patterns of loading. No meaningful relationship based on individual attributes could be established.

Hendrickson, C., and Plank, E. (1984). "The Flexibility of Departure Times for Work Trips." *Transportation Research A*, 18A(1), 25-36.

In this paper, a set of data gathered in Pittsburgh, PA is used to analyze dynamic level of service variations and departure time decisions. Collecting this data set involved independent measurement of travel times and transit wait times for travel to the Pittsburgh Central Business District (CBD) as well as a survey of 1800 workers in the CBD. To measure travel times into the CBD, at least eight vehicle trips were made from each of four suburban areas during the morning peak period of travel. The variability of travel times for a given departure time was relatively low. The pattern of expected wait times for transit and the variance of wait times depended strongly on local operating policies. The variance of wait time with scheduled service depended strongly on the frequency of service. With scheduled transit departures quite frequent, the variance of wait time was relatively low.

To further analyze traveler decisions, a logit model of mode choice and departure time was estimated. The base model included up to twenty-eight alternatives representing combinations of four modes (drive alone auto, shared ride, transit with walk access and transit with auto access) and seven different departure time intervals of 10 minutes each. In this analysis, mode and departure time choices were treated as a simultaneous interactive decision. The modal utility included free flow in-vehicle travel time, the portion of total travel time due to congestion associated with travel at a particular departure time, monetary cost divided by household income, walking time on the home end of a transit trip, wait time, minutes of late arrival at work with a quadratic function of that, and minutes of early arrival at work with a quadratic function of that.

The estimation results show high statistical significance for most of the coefficients. The coefficients of free flow and congested travel times are insignificant. This result may be due to the similarity of in-vehicle travel times for the different modes in the data set. Values of times were calculated from the estimated coefficients. Elasticity values were also calculated.

In addition, the logit model can be used to indicate the effects of new policies such as tolls, exclusive bus lanes, or changes in congestion. The study reports the effects of various policy changes on travel from one of the suburban areas in Pittsburgh. Observations of traveler responses to disruptions, demand theory and the empirical demand models reported in this study all suggest that individuals can exhibit flexibility in the choice of departure time for work. The departure time decision seems to be more elastic than the choice of mode.

Horowitz, A. J. (1978). "The Subjective Value of the Time Spent in Travel." *Transportation Research*, 12, 385-393.

This study employs a psychological scaling method, known as magnitude estimation, to evaluate how individuals subjectively value the time spent in travel. The study addresses how the value of time spent in travel varies as a function of trip length, time period, trip purpose, travel mode and environmental conditions. Subjective value of time is akin to a psychological utility scale of travel time. It is derived from responses to a psychological scaling task and differs from the monetary values that are most often inferred from revealed behavior. Subjective value as presented in this study is an arbitrary ratio scale and does not explicitly consider monetary tradeoffs. The important advantage of such a limitation is an isolation of travel time effects from other utility considerations. The disadvantage is that subjective values can not be directly used in cost-benefit analyses without a some monetary transformation. Subjective values are quantified through psychophysical measurement.

A questionnaire was prepared for 84 Chicago residents asking for magnitude estimates of described trips. The standard stimulus in each questionnaire was personalized so that it represented a common trip for each individual. Twelve different standard stimuli were employed. Work trips were used as standard stimuli for those who worked. Otherwise, the standard stimulus was specified as a shopping trip. Thus, all questions required subjects to compare a hypothetical trip against a familiar standard stimulus. The comparative stimuli represent four two-way factorial designs and one additional one-way factorial design. All combinations of levels for two factors comprise the question within each design. The four two-way designs were (i) mode by time lengths for work trips; (ii) mode by non-work purpose for 30 minute weekend trips; (iii) time period by non-work purpose for 30 minute trips by automobile; (iv) time length by non-work purpose for 30 minute trips by automobile. The one-way design was environmental conditions. Any single subject was administered only a subset of all possible comparative stimuli.

Statistical analyses were performed on logarithmically transformed variables. The logarithmic transformation further allows inclusion of the standard stimulus directly as a factor in the analyses of variance. The first four factorial designs consisted of questions that varied two trip attributes. With the exception of the time period factor, all main effects are significant. Four of twelve interaction terms in the four analyses of variance were significant. The standard mode interaction terms in both the work and non-work trip analyses were significant. Except for evaluations on mode of travel, the standard stimulus had a multiplicative effect on responses. Two other significant interactions demonstrated that a simple multiplicative analysis of variance model is not necessarily the best description of the data. Time length of trips interacts significantly with mode of travel on work trips and purpose on non-work trips. This indicated that time length should be treated differently depending upon the mode and purpose of the trip.

Analysis of the one-way factorial design testing the effect of environmental conditions on travel showed it to be significant.

The analyses of variance demonstrate that models of the subjective value of the time spent in travel can be constructed. A regression model was used for this purpose. The insignificance of the interaction terms between trip attributes suggests that these models should be multiplicative. The major exceptions, interaction between time and mode and time and purpose, are dealt with by introducing time as a covariate within the regression model. Four such models were constructed and estimated for the four factorial designs, and subjective values of time for different conditions were inferred from the model results.

Iida, Y., Uno, N., and Yamada, T. (1999). "Experimental Analysis of Effects of Travel Time Information on Dynamic Route Choice Behavior." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 215-239.

The objectives of this study are to identify the change in drivers' route choice decision-making following the introduction of a traveler information system, and to determine the influence of the accuracy of provided information on decision-making. The study was designed to clarify the influence of drivers' knowledge acquired through repeated trips and to control the accuracy of provided information. To this end, time series data on the subject's route choice were collected using a simple PC-based simulator.

In the experiment, a subject repeatedly traveled (in the simulator) between the same origin and the destination in the morning. Over successive trips, the subject learned about, and accumulated knowledge of, the network and information system. Accordingly, it was likely that the subject's route choice mechanism was influenced by this knowledge. In order to clarify the influence of the learning process and acquired knowledge on route choice behavior, it was necessary to observe continuously the route choice behavior of the same subject over a certain number of experimental repetitions, and to analyze the collected time series data.

The basic findings of the study are the following:

- the provision of real-time information about traffic conditions through dynamic traffic information systems changes drivers' route choice mechanism greatly;

- it is likely that drivers' route choice mechanisms, when formed under information provision, is influenced by the accuracy of provided information. In particular, it was noted that the route choice mechanism becomes strongly dependent on information if highly accurate information is provided continuously. Conversely, there is a risk that inaccurate information deteriorates the value of information system installed; and

- the route choice mechanism, once formed, does not change in a short period of time, even after a change in the accuracy of information. It is concluded that a kind of inertia limits the speed with which route choice mechanisms change in response to a change in the accuracy of provided information.

Iida, Y., Akiyama, T., and Uchida, T. (1992). "Experimental Analysis of Dynamic Route Choice Behavior." *Transportation Research B*, 26B(1), 17-32.

Drivers' route choice behavior is influenced by their experiences accumulated in daily driving. This study analyzes dynamic route choice behavior and the resulting traffic flows in a two-route network by conducting experiments that repeatedly ask the participants to make hypothetical route choices. In each repetition of the experiment, each of a set of participants is asked to predict the travel time on the alternative routes and to choose a route, based on prior experience. Total traffic flow on each route is obtained by aggregating the choices, and actual travel time on each route is calculated from the traffic flow. Participants are then told the actual travel time on their chosen routes. The difference between actual and predicted times will affect, as travel experience, the participant's prediction of travel time and route choice in subsequent situations. The experiment repeats this procedure a number of times.

Two experimental setups are used. They differ in the travel time information presented to the participants. In Experiment 1, only the actual travel time from the last iteration is presented. In contrast, the entire history of both actual and predicted travel times is provided in Experiment 2. Since traffic flow is always fluctuating, it is difficult to predict travel time. Therefore, the driver must choose his route based upon subjective experience and imperfect traffic information. The objectives of the study are to determine the effect of accumulated experience and of different types of information on the evolution of traffic flow in the network, and to investigate whether equilibrium is achieved over time.

In Experiment 1, where route choice is based only on the last iteration's experience, the evolution of route traffic volume continuously shows considerable oscillation and is not likely to converge. On the other hand, in Experiment 2, where route choice is based on all the prior experience, the variation in traffic volume becomes considerably smaller, despite continuing variability in route choice behavior. However, it is not certain that additional repetitions of this experiment would lead to an equilibrium.

Results also indicate that route switching behavior depends on route characteristics. The route switching rate increases with increases in the actual travel time and in the predicted travel time error. The relationship is almost linear between the predicted travel time error and the adjustment from the actual travel time to the next predicted travel time.

Kantowitz, B. H., Hanowski, R. J., and Kantowitz, S. C. (1997). "Driver Acceptance of Unreliable Traffic Information in Familiar and Unfamiliar Settings." *Human Factors*, 39(2), 164-176.

Kantowitz, B. H., Hanowski, R. J., and Kantowitz, S. C. (1997). "Driver Reliability Requirements for Traffic Advisory Information." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 1-22.

The goal of the research described in these two papers is to provide answers to the following questions: (i) how reliable must traffic information be for motorists to trust and use it? and (ii) how does the familiarity of the setting influence trust and use of unreliable traffic information? The authors express a driver's decision to utilize ATIS messages or not as matter of the relative strengths of the driver's self-confidence and his or her trust in the ATIS.

To obtain data pertinent to these questions, the authors carried out travel choice simulation experiments using the Battelle Route Guidance Simulator (RGS), a computer-based partial-task simulator. A driver's immediate driving environment and the network location are shown (two monitors are used), the driver receives information on link traffic conditions (expressed simply as heavy or light traffic) and makes a route choice, which is recorded. Note that an error in reporting the traffic conditions may be harmful (link traffic is reported to be light when in fact it is heavy) or benign.

In the experiments described here, the quality of the information provided was intentionally degraded: in one case, 71% of the link traffic reports were accurate, and in another only 43% of the reports were accurate. (Completely accurate reports were also provided in some runs.) Furthermore, the simulator could display realistic visual scenes from the Seattle network (experimental subjects were chosen to be people who had considerable experience driving in the Seattle area), or unfamiliar scenes for a network that was topologically similar to the Seattle network.

It was found that drivers will utilize ATIS messages even if they are known not to be accurate. Specifically, information that is 71% accurate (in the sense defined above) remains useful to drivers. However, when the information accuracy drops to 43%, driver performance, trust in and use of the system suffer. Drivers did not use accurate information as effectively in the familiar setting as in the unfamiliar setting. Also, inaccurate traffic information was more harmful in a familiar setting. Because drivers have greater self-confidence in familiar settings, they are more critical of ATIS messages and hold it to a higher standard of acceptability.

Katsikopoulos, K. V., Duse-Anthony, Y., Fisher, D. L., and Duffy, S. A. (2000). "The Framing of Drivers' Route Choices when Travel Time Information is Provided under Varying Degrees of Cognitive Load." *Human Factors*, 42(3), 470-481.

In this study drivers' route choice behavior is investigated when travel time information is provided under varying degrees of cognitive load. In this study travel time variability is presented by giving drivers a range of possible travel times for routes with an uncertain travel time. A route (main) with a certain travel time and a route (alternate) that could take a range of travel times are described. This study investigates the effects of average travel time and travel time variability. Scenarios were considered in which the average travel time of the alternative route was smaller than, equal to, and greater than the certain travel time of the main route. Attempts were made to determine whether the effect of range is a function not only of framing but also of the cost of being late. This research also tests whether participants make the same choices while driving as they do when sitting still.

In the first experiment, a stated preference approach and a paper-and-pencil task was used. The main goals were to – a) verify that drivers attempt to minimize their average travel time when travel time variability is presented as a range of travel times, b) verify that drivers prefer smaller ranges in the domain of gains, and c) test whether drivers prefer greater ranges in the domain of losses. In the second experiment, a driving simulator was used where travel time information was displayed in a virtual environment through which participants drove. It was hypothesized that the increase in cognitive load would reduce the importance of at least one of the route attributes that drivers consider when making a decision. Drivers may have enough reserve capacity to compute only the average travel time along the alternative route during the majority of scenarios. There may be some scenarios in which they also examine the range, but this effect would be attenuated.

It was found that drivers attempt to minimize their average travel time when travel time variability is presented as range of travel times and that drivers prefer smaller ranges in the domain of gains. The average travel time on the alternative route has a particularly large effect on both the driving simulator and the paper-and-pencil task. By contrast, the range of the alternative route has an effect that is practically very large on the paper-and-pencil task but relatively small on the driving simulator task.

Overall, participants were risk averse when the average travel time along the alternative route was shorter than the certain travel time of the main route but risk-seeking when the average travel time of the alternative route was longer than the certain travel time along the main route. In the second experiment, when the cognitive load was higher, participants simplified their decision making strategies. A simple probabilistic model describes the risk taking behavior and the load effects.

Kaufman, D. E., Smith, R. L., and Wunderlich, K. E. (1991). "An Iterative Routing/Assignment Method for Anticipatory Real-Time Route Guidance." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 693-700.

This article describes the SAVaNT (Simulation of Anticipatory Network Vehicle Traffic) route guidance method. SAVaNT models guided and unguided vehicle classes. Unguided vehicles are assumed to follow minimum paths based on free-flow travel times, while guided vehicles are assumed to comply fully with time-dependent minimum time path recommendations available at every network node; a single path is computed for each node-destination pair and each time step. In short, savant assumes fully informed choice by guided vehicles and so can be considered a deterministic user-optimal full information model with fixed route background traffic consisting of unguided vehicles. However, the authors presented it as a route guidance system and as such used it to highlight and discuss issues such as guidance consistency.

Savant uses a mesoscopic traffic simulator, INTEGRATION, to move vehicles along their paths and to determine the resulting traffic conditions. The version of INTEGRATION used by the authors was essentially deterministic. To generate guidance, time-dependent minimum paths are computed and guided vehicles are moved along them, resulting in a new set of conditions and new minimum paths, which in turn are used to compute minimum paths in the next iteration. Because of the deterministic dynamics, together with the use of single-path guidance and the assumption of full driver compliance, the guidance generation process evolves deterministically, and can assume only a finite number of states following initialization. Thus, it must either converge to a fixed point (the minimum paths are repeated in iterations k and k+1) or cycle (minimum paths are repeated in iterations k and k+n, n>1). In fact the authors found that savant invariable cycles when using the time-dependent link traversal times from the mesoscopic simulator as the basis for the minimum path calculation.

In many ways, this paper was a seminal work. It was one of the earliest articles to recognize the issue of consistency in anticipatory guidance, and it identified guidance generation as a fixed point problem over a composite routing-assignment map. On the other hand, by adopting a conventional dynamic traffic assignment framework, it assumed that guidance information is perfect (available everywhere, precise, accurate and up-to-date). Furthermore, it was based on a particularly simple assumption of driver response to information (full compliance with minimum path routing). Finally, the fixed point solution algorithm was not generally convergent.

Kaysi, I., Ben-Akiva, M., and Koutsopoulos, H. (1993). "Integrated Approach to Vehicle Routing and Congestion Prediction for Real-Time Driver Guidance." *Transportation Research Record*, 1408, 66-74.

This paper proposes a functional design of an anticipatory guidance generation system at a high level of detail. The system consists of a network of traffic measurement devices, a database of information on network characteristics and historical O-D flows, guidance dissemination technology such as VMS or radio communications, and inter-connected computational modules that are executed in a traffic information center. These computational components include a module for updating historical O-D data using real-time measurements, a congestion prediction (COP) module and a control and routing (CAR) module. The COP module forecasts short- and medium-term dynamic traffic conditions from the updated "3D" (i.e., time-dependent) O-D data, and taking into account any guidance messages that are disseminated. The CAR module takes short- and medium-term traffic condition forecasts and generates guidance messages based on them; it also ensures consistency between forecasts and guidance.

Principles underlying the proposed approach include:

- the COP should provide CAR with projected traffic conditions;
- a DTA model should be used for COP; and
- the CAR should maintain consistency between the generated guidance and the COP's traffic condition predictions.

Referring specifically to the use of a DTA model for congestion prediction, the authors note that DTA model must be able to capture the effect on drivers' behavior of guidance messages that they receive; however, they do not propose specific models of driver response to guidance. The model should also be able to be initialized with arbitrary current traffic conditions, should account for traffic control measures in effect, and should allow link capacities to be adjusted to account for incidents detected in real-time.

Khattak, A. J., Schofer, J. L., and Koppelman, F. S. (1992). "Factors Influencing Commuters' En Route Diversion Behavior in Response to Delay." *Transportation Research Record*, 1318, 125-136.

Khattak, A. J., Koppelman, F. S., and Schofer, J. L. (1993). "Stated preferences for investigating commuters' diversion propensity." *Transportation*, 20(2), 107-127.

The article (Khattak, Koppelman et al. 1993) investigates factors that influence auto commuters' en route diversion propensity. Data on propensity to divert and related factors were collected through a questionnaire survey. Downtown Chicago auto commuters were targeted. The Chicago area offered a relatively conducive environment for studying drivers' en route diversion decisions due to the availability of quantitative real-time traffic information on freeway links. Further, the road network in Chicago usually offers real choices between several alternative routes. The stated preference (SP) approach was used to study diversion propensity. The effects of incidents and recurring congestion, real-time traffic information, driver and roadway characteristics and situational factors on drivers' willingness to divert were investigated.

This research is based on conjoint measurement, a commonly used stated preference technique where two or more attributes of alternatives are considered jointly. A paired comparison conjoint approach that considers different levels of one attribute at a time was used, due to the exploratory nature of this study, the need to test several attributes and the simplicity of the method. Each attribute had two levels. Possible combinations of attributes and interaction effects were not explored.

Multivariate models of diversion propensity were estimated to explore the effects of several variables simultaneously. The multivariate model used was an ordered probit model with diversion propensity as a function of delay characteristics, reported trip and route attributes and socio-economic characteristics of the respondent drivers. The ordered probit model was selected for estimation because of its ability to analyze ordered categorical response data. Use of the multinomial logit or probit models or linear regression may lead to biases in estimation.

The results indicated that drivers expressed a higher willingness to divert if the congestion was incident-induced as opposed to recurring, delay information was received from radio traffic reports compared with observation of congestion, trip direction was home to work as opposed to work to home and delays on usual route increased. Respondents were less willing to divert if their alternate route was unfamiliar, unsafe or had traffic stops. Socio-economic and trip attributes significantly influenced drivers' willingness to divert.

Some of the findings can be used to formulate initial policy guidelines for developing advanced traveler information systems. Drivers were more willing to divert in response to incident congestion, suggesting that normal route choice decisions may not account for incident-induced congestion. This implies that ATIS should improve the capability to detect incidents and disseminate incident-related information in a timely manner.

The article (Khattak, Schofer et al. 1992) is very similar to the one previously described. Commuter response to delay was investigated in real-life situations to explore the effects of factors such as driver and trip characteristics, route attributes, traffic information, and environmental conditions on driver response to delay. This research examines the effect of several variables on the diversion decision by estimating diversion choice models based on respondents' reported experience of a recent delay.

En-route diversion behavior was found to be influenced by several factors, including source of traffic information, length of delay, gender, travel time, number of alternate routes used, congestion on the alternate route, residential location, self-evaluation statements about risk behavior, and stated preference about diverting. The key finding is that real-time traffic information can influence en-route diversion behavior. Drivers were more likely to divert when they received delay information through radio reports than when they observed the delay.

Khattak, A. J., Schofer, J. L., and Koppelman, F. S. (1993). "Commuters' Enroute Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems." *Transportation Research A*, 27A(2), 101-111.

Abdel-Aty, M. A. (1998). "Modeling Incident-Related Routing Decisions by Using a Nested Logit Structure." *Transportation Research Record*, 1645, 103-110.

The objective of the study described in (Khattak, Schofer et al. 1993) is to identify factors that influence auto commuters' en-route decisions to divert from their regular route in response to information about incidents, and factors that influence a subsequent decision to return to the regular route after diversion. Data from a survey of automobile commuters in downtown Chicago are used to develop models of diversions and return behavior.

Temporal knowledge of travel conditions relates to individuals' expectations of travel time and traffic congestion at different times of day along a route. Due to "perturbations" in travel conditions caused by incidents, drivers may modify their intended travel choices. En-route decision-making also entails the choice of returning to the usual route after diversion. This research focuses on situations where drivers had the choice of either returning to their usual route or continuing on their alternate route. It hypothesizes that diversion and return choices may be influenced by source of information, attributes of routes, individual characteristics, trip characteristics, situational factors, and environmental conditions. Data were collected to test the behavioral hypotheses empirically through a survey of Chicago commuters.

This paper examines diversion and return choices. The model structure represents these as interrelated choices to account for the possibility that drivers' diversion choices will depend, in part, on their expectation that they will or will not return to the original route. That is, the driver chooses among three alternatives: no diversion, diversion and no return, and diversion and return. Two model forms were considered: a joint multinomial logit model among these three alternatives and a nested logit model in which the return choice is nested within the diversion decision. Both these models with equivalent specification were estimated and their estimation results were compared yielding very similar coefficient values (i.e. essentially identical behavioral interpretation).

Commuters' diversion and return behavior varied with their personal characteristics and the characteristics of the trip they were making at the time when the choice arose. Individuals were significantly more likely to divert if they were oriented to "adventure and discovery", stated a higher preference for diversion and were familiar with multiple routes. Individuals making longer trips, facing longer delays and facing less expected congestion on alternate routes were more likely to divert. Commuters who made longer trips were significantly more likely to return after diversion. Individuals who used radio traffic information, and those with higher stated preference for diversion were more likely, but not significantly so, to return to their original route. Individuals oriented to “adventure and discovery” were slightly less likely than others to return to their original route.

The paper (Abdel-Aty 1998) is similar to the one described above as it addresses drivers’ diversion and return choices using alternative model forms. This study considers three diversion options in an incident situation: no diversion (ND), diversion and return (DR) and diversion and no return (DNR). It investigates different logit model forms to represent these options: whether a multinomial logit or a nested logit model is appropriate, and what type of nesting structure should be applied to such a problem. Data were collected by using a telephone survey of 564 Los Angeles morning commuters.

In addition to the joint multinomial logit, two alternative nesting structures were tested. In one, the DR and DNR choices were grouped in a “diversion” nest, since in both cases the decision to divert has occurred. In the other, the ND and the DR choices were group in a “stay on the route” nest, since in both cases the driver prefers the route, the diversion being simply a detour around a local impediment.

It was concluded that the nested logit model that account for shared unobserved effects between ND and DR provided the best structural fit for the observed distribution of the routing decision in case of an incident. The superiority of the nested logit structure over the simple MNL was proved. The variables that entered in the estimated models illustrate the significance of socioeconomic, commuting and perceptual factors on the incident-related routing decisions. A consistently significant factor is the traffic information acquisition. This shows that ATIS may have a significant effect on traffic re-routing in case of incidents.

Khattak, A. J., Kanafani, A., and Le Colletter, E. (1994). "Stated and Reported Route Diversion Behavior: Implications of Benefits of Advanced Traveler Information Systems." *Transportation Research Record*, 1464, 28-35.

The benefits of ATIS accrue to system users and nonusers and to the transportation system as a whole. Among the possible user benefits of ATIS are travel time savings from fewer errors when driving in unfamiliar areas and from avoiding unexpected congestion. Transportation system benefits of ATIS may include area-wide reductions in trip time, air pollution and energy consumption, as well as greater safety. This study focuses on the user benefits of route diversion. Although a wider definition of ATIS user benefits is possible, only time saving for people with access to ATIS devices is considered. The extent to which user and system benefits of ATIS can be achieved is a function of how travelers respond to information. Some of the questions that are addressed in this research are following: Is descriptive information enough? Are drivers willing to follow prescriptive information? Does information about future travel time increase the propensity to divert?

This paper is based on a survey about commuting behavior undertaken in the San Francisco Bay Area in 1993. The questionnaires were distributed to peak period commuters crossing the Golden Gate Bridge during morning and afternoon rush hours. The questionnaire was designed to use reported diversion behavior (considered as an indicator of true behavior) as the basis of a sequence of stated preference questions about the propensity to divert with a future in-vehicle ATIS device. This methodology increases the validity of the stated preference technique by relating the response to ATIS technology to a specific incident that was actually experienced by the respondent. The objective of the stated preference question was to determine how incremental amounts of information provided by an ATIS device would influence the propensity to divert. It appeared that respondents overstated their propensity to divert when compared with reported behavior. 22% of the respondents stated that they would divert even though they reported not having diverted. On the other hand, only 5% of the people stated that they would not divert even though they actually diverted when they faced the unexpected delay.

To explore the correlation between reported behavior and stated preference, a linear regression model relating the answers to each question was developed. All observations from the reported behavior and from the five stated preference questions were stacked in a single column vector. This vector was then related to a sequence of five dummy variables, flagging one when the observation was from the specific stated preference question. The coefficients obtained reflect the influence of each stated preference variable in explaining the vector of observations and the increase in the probability of diversion given the additional information provided.

75% of the respondents reported that they faced unexpected congestion on their usual route to work at least once in the past three months. 21% of them reported that they then had an opportunity to divert, and 16% did divert. 33% stated they would divert if provided with ATIS qualitative information at the beginning of their trip. More diversion is obtained in the stated preference case, partly because respondents had the benefit of hindsight and had more opportunities to divert because they were starting their trip over. There might also be a tendency to overstate diversion behavior. The stated preference questions showed that the more complete the travel information, the higher the proportion of commuters diverting under unexpected congestion. Almost 70% of the people stated they would divert when the device provided quantitative real-time information on their usual route plus travel time on their alternative routes. Under incident conditions, prescriptive information might be sufficient to achieve high diversion rates. However, driver compliance with prescriptive information will be conditional on the effectiveness (reliability and accuracy) of ATIS in suggesting better routes. Potential annual monetary benefits from ATIS induced diversion in the Golden Gate Bridge corridor range from $124 to $324 per person, varying linearly with the weight assumed for delay. These figures apply to about 40% of the commuting population in the corridor.

Khattak, A. J., Schofer, J. L., and Koppelman, F. S. (1995). "Effect of Traffic Information on Commuters' Propensity to Change Route and Departure Time." *Journal of Advanced Transportation*, 29(2), 193-212.

Khattak, A. J., Schofer, J. L., and Koppelman, F. S. (1991). "Effect of Traffic Reports on Commuters' Route and Departure Time Changes." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 669-679.

(These two articles are very similar.)

This study evaluates the effect of conventional traffic information (radio traffic reports and VMSs) on travelers' route and departure time changes.

Downtown Chicago automobile commuters were surveyed during the AM peak period using a mail-back questionnaire method. Drivers were asked to note whether or not they had changed their route and departure time decisions based on traffic reports. They were also asked to indicate how they perceived the traffic information system, and to evaluate alternative possible improvements to it.

The results indicated that a majority of the respondents access, use and respond to information. More than 60% of the respondents had used traffic information to modify their travel decisions. Drivers rated radio traffic reports positively. Multivariate analysis using the ordered probit model showed that individuals were more likely to use traffic reports for their route changes if they perceived traffic reports to be accurate and timely, and frequently listened to traffic reports. Respondents were more likely to change their departure times if they perceived traffic reports to be accurate and relevant, and frequently listened to traffic reports. Males and high income travelers were more likely to use traffic reports to modify travel decisions.

Some individuals reported using travel information, not to change travel decisions, but rather to reduce their anxiety. This indicates that simply knowing traffic conditions is valued by travelers, and shows that such information may have an intrinsic value.

Drivers indicated a relatively lower level of satisfaction with traffic reports that made suggestions for alternate routes. The authors suggest two possible types of ATIS information that may be particularly beneficial: near-term predictions of traffic conditions on congested routes with rapidly-changing traffic conditions; and estimates of incident durations.

Khattak, A. J., Y. Yim, et al. (1999). “Does Travel Information Influence Commuter and Noncommuter Behavior? Results from the San Francisco Bay Area TravInfo Project.” Transportation Research Record **1694**: 48-58.

A CATI survey of residents of the nine-county San Francisco Bay Area was conducted. 947 useable responses were obtained. Respondents were categorized into four groups by usual mode choice and trip purpose: automobile commuters (AC), transit commuters (TC), automobile non-commuters (ANC) and transit non-commuters (TNC). Respondents were asked questions about their typical trip characteristics, and then about their access to and response to travel information. Radio, television and telephone information sources were considered. The study analyzed the impacts of socioeconomic, context and information variables on individuals' decisions to adjust travel before beginning their trips; given an adjustment, the frequency of trip changes; and the type of the most recent trip changes in terms of route, departure time or mode shifts. Different questions were asked depending on the type of respondents.

Multinomial probit and logit models were estimated from the survey data. Among other conclusions, it was found that:

- a significant portion of respondents (between 18 and 52 percent, depending on mode and trip purpose) do not divert because of travel information;
- the propensity to adjust pre-trip decisions is highest for commuters;
- individuals who experience higher travel time uncertainty and reported the occurrence of unexpected delays during the past month have a higher propensity to make pre-trip decision changes in response to travel information;
- receipt of travel information from radio reports (as opposed to television and telephone) increases the frequency of pre-trip changes for automobile and transit commuters, and automobile non-commuters;
- individual with longer reported travel times in severe traffic conditions are more likely to change their departure times and routes;
- non-commuters and radio listeners are most likely to cancel their trips in response to information.

In general, it was found that information from radio was the most likely to result in pre-trip decision adjustments, and that non-commuters have a high receptivity to canceling their trips in response to travel information.

Kitamura, R., Jovanis, P. P., Abdel-Aty, M., Vaughn, K. M., and Reddy, P. (1999). "Impacts of Pre-trip and En-route Information on Commuters' Travel Decisions: Summary of Laboratory and Survey-based Experiments from California." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 241-267.

Abdel-Aty, M. A., Vaughn, K. M., and Jovanis, P. P. (1993). "Understanding Traveler Responses to Advanced Traveler Information Systems (ATIS)." 26th International Symposium on Automotive Technology and Automation, Dedicated Conference on Advanced Transport Telematics/Intelligent Vehicle Highway Systems -- Towards Development and Implementation, Aachen, Germany, 245-252.

Yang, H., Kitamura, R., Jovanis, P. P., Vaughn, K. M., Abdel-Aty, M. A., and Reddy, P. (1993). "Exploration of Driver Route Choice with Advanced Traveler Information Using Neural Network Concepts." *UCB-ITS-PRR-93-13*, California PATH Program, Institute of Transportation Studies, University of California, Berkeley.

Abdel-Aty, M. A., Kitamura, R., Jovanis, P. P., and Vaughn, K. M. (1994). "Investigation of Criteria Influencing Route Choice: Initial Analysis Using Revealed and Stated Preference Data." *UCD-ITS-RR-94-12*, Institute of Transportation Studies, University of California, Davis.

Abdel-Aty, M. A., Kitamura, R., and Jovanis, P. P. "Investigating the Effect of Travel Time Variability on Route Choice Using Repeated-Measurement Stated Preference Data." *Transportation Research Board 74th Annual Meeting*.

Abdel-Aty, M. A., Kitamura, R., and Jovanis, P. P. "Route Choice Models Using GIS-based Alternative Routes and Hypothetical Travel Time Information Input." *Transportation Research Board 74th Annual Meeting*.

Abdel-Aty, M. A., Vaughn, K. M., Kitamura, R., Jovanis, P. P., and Mannering, F. L. (1994). "Models of Commuters' Information Use and Route Choice: Initial Results Based on Southern California Commuter Route Choice Survey." *Transportation Research Record*, 1453, 46-55.

Abdel-Aty, M. A., Vaughn, K. M., Jovanis, P. P., Kitamura, R., and Mannering, F. L. (1994). "Impact of Traffic Information on Commuters' Behavior: Empirical Results from Southern California and Their Implications for ATIS." Proceedings of the 4th Annual Meeting of IVHS America, 823-830.

Abdel-Aty, M. A., Kitamura, R., and Jovanis, P. P. (1995). "Understanding the Effect of ATIS on Commuters' Route Choice Decisions." Proceedings of the 5th Annual Meeting of ITS America, 237-245.

The first paper presents results and conclusions from a California PATH project studying the impact of ATIS on travel demand, and summarizes a number of more detailed papers by the study team. The focus of the project is travelers' behavioral response to ATIS information. Two parallel studies were undertaken as part of the project:

- analysis of driver decisions in response to ATIS information using computer simulation experiments; and

- analysis of commuters' information acquisition, perception of route attributes and route choice behavior.

The objective of the second analysis was to improve understanding of drivers' route choice behavior as it is influenced by perceptions of different route attributes. An additional objective was to establish how much information drivers have, and how much dynamic information they acquire before making a route choice. This work was based on multiphase telephone interview and mail surveys of commuters in the Los Angeles metropolitan area.

The objective of the first analysis was to better understand how drivers use ATIS information, including factors that influence drivers' responses. This analysis was conducted using data obtained from travel choice simulation experiments in which subjects "drove" repeatedly through the same network, but under different simulated traffic conditions. A model system was developed using this data.

Two sets of computer-based travel choice simulation experiments were conducted.

In the first, subjects were presented with a simple (but unfamiliar) network comprising two alternative routes, and choose between the two routes over a series of repeated trials (Vaughn, Abdel-Aty et al. 1993b). VMS-type prescriptive route recommendations were provided, but subjects were warned that the information would not always be correct. Factors included in the experimental design were: accuracy (percentage of correct recommendations); inclusion or not of a justification for the recommendation; provision of post-trip feedback or not; inclusion or not of a stop on one of the routes; freeway effect (one of the routes was designated as a freeway in the simulator) or not; and provision of area context (a diagram showing the origin and destination linked by the two routes) or not. Sixteen combinations of factor levels were chosen, and at least 20 subjects were used for each combination, where each subject "drove" through the network 32 times. In each trial, a random delay was assigned to each route, the subject was given a route recommendation and his or her compliance was directly measured. The delay was distributed over the two trials such that the two routes had the same mean but differing variances. After the 32 trials were completed, the subjects were asked to rate their perception of the accuracy of the guidance, their own ability to select a route compared to the guidance, and their potential for purchasing a guidance device.

The second set of simulation experiments used a more complex network consisting of 3 parallel facilities connecting an origin to a destination, with numerous opportunities to switch from one facility to another en route. The travel environment was generated by a random assignment of travel speeds and stop delays to the network links and nodes. Incidents were generated randomly. For these experiments the computer monitor depicted an in-vehicle information system. The types of information included incident information, en route recommendations, pre-trip recommendations, and congestion level information. Experimental factors included: display or not of incident information; provision or not of en route guidance (turning movement recommendations at each node); provision or not of pre-trip guidance (identification of shortest origin-destination path); display or not of congestion information for each link; demographics (variations in gender, age and education). Each subject went through 20 repeated trails under the same combination of treatment factors. Incident location was always provided accurately, but route guidance and congestion information was incorrect 25% of the time. Subjects' decisions were recorded along with relevant context descriptors, and at the end of a trial subjects were again asked questions about their perceptions of the information received and their willingness to purchase a system.

In addition to the simulation experiments, data on the actual route choice behavior of commuters was collected in three waves of route choice surveys of a fixed set of commuters: the first two conducted with CATI interviews, and the third with mail-back questionnaires, with questions tailored to each respondent based on answers given in the CATI interviews. The first wave CATI survey obtained information about the usual and alternative commute routes and their attributes, socio-economic characteristics, and conventional traffic information sources and their influence on behavior. The second wave CATI survey identified any changes in commute characteristics, investigated respondents' perceptions of various attributes of the commute trip, and included the effects of uncertainty on commute route choice decision-making. The third wave mail-back survey showed each respondent optimum (minimum path) commute routes generated by a GIS and asked about the respondent's knowledge of and preference towards these routes. It also asked SP route choice questions involving information availability from a hypothetical ATIS.

A number of findings resulted from analyses of the data generated by these different data collection efforts.

From the first travel choice simulator experiments, it was found that compliance with guidance increases with information accuracy up to the 75% level, and more slowly thereafter.

Experienced drivers complied less than inexperienced drivers; however less experienced were less likely to say they would buy an ATIS device. Subjects were more willing to accept advice to take the freeway than to take other routes. Perception of information accuracy was strongly affected by past experiences in addition to the most recent experience. Giving an explanation for a route recommendation, giving feedback about choices made and increasing the level of information all significantly increased the compliance rate and the willingness to purchase a system.

From the second travel choice simulator experiments, it was found that incident information and congestion information were valued most highly, while pre-trip and en route guidance recommendations were valued less; however, including descriptive information with prescriptive recommendations increased the compliance rates significantly. User perceptions of the system accuracy level increased when incident information was provided, and when descriptive and prescriptive information were provided together. Almost half the respondents indicated that they were "very likely" or "likely" to purchase an ATIS. There was higher willingness to pay for systems that provided a variety of message types. Males and younger people tended to value the systems more highly, those with high incomes valued it less highly.

Route choice models (generally random parameter logit models with normal mixing distributions) were estimated from the commuter surveys. In general, it was found that subjective perceptions of route attributes affected route choice; perceived travel time reliability and traffic conditions were important, along with travel time and the number of roadway segments on the commute route. The probability of trying an alternative route increased with the length of the commute. Travel time difference and freeway bias were the two most significant explanatory variables in predicting route choices.

Investigations of the influence of travel time reliability on route choice using results of SP questions showed that the reliability of a route (as measured, for example, by the standard deviation of its actual travel times) influenced its choice roughly as much as the travel time itself. However, those who receive pre-trip information tend to choose the route with higher a priori travel time standard deviation.

Further work examined joint information acquisition and route switching behavior. Bivariate probit models were developed to determine the factors that influence information use and the propensity to take alternative routes. Acquisition of pre-trip information was associated with trip-makers who travel a long distance and who perceive travel time uncertainty as a major problem. Those who perceived little variation in traffic conditions on their commute routes tended not to acquire pre-trip information. Acquisition of en route information was associated with the same conditions. It was also found that commuters who received pre-trip information were, other things equal, less likely to receive en-route information as well. However, those who showed themselves more likely to acquire pre-trip information than expected from their personal and trip characteristics, were also more likely than expected to acquire en route information, and vice versa.

Route switching frequency was investigated using negative binomial regression models, one developed for travelers who receive pre-trip information, the other for those who receive en route information. Pre-trip information increased the route switching propensity of those who perceived traffic reports as accurate and those for whom the travel time on the primary route was longer. En route information increased the route switching propensity of those who perceived traffic reports as accurate, and those who carpooled.

Diversion behavior in incident situations was also studied. It was found that commuters who gave high priority to not driving through unsafe neighborhoods were less likely to divert, whereas carpoolers and those who received en route information were more likely to divert around the incident.

Kobayashi, K. (1993). "Incomplete Information and Logistical Network Equilibria." The Cosmo-Creative Society: Logistical Networks in a Dynamic Economy, A. E. Andersson, D. F. Batten, K. Kobayashi, and K. Yoshikawa, eds., Springer-Verlag, 95-119.

Kobayashi, K. (1994). "Information, rational expectations and network equilibria---an analytical perspective for route guidance systems." *Annals of Regional Science*, 28, 369-393.

Kobayashi, K., and Tatano, H. (1999). "Information and Rational Expectations in Modelling Driver Information Systems: A Welfare Measurement." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 69-92.

The rational expectations hypothesis (REH) was introduced in economic theory by Muth in 1961. It applies to situations in which the behavior of an economic agent with incomplete information is determined in part by the agent's expectations about the future state of the economy – and this behavior, of course, influences in turn the future state of the economy. The REH postulates that, over time, an economic agent develops an internal model of the economy that wills it to make inferences about the probability distributions of economic variables from publicly-available information. These inferences are derived, implicitly or explicitly, from an agent's internal model of the relationship between the (limited) information that it receives and the actual state of the economy. On the other hand, the true relationship is determined by individual agents' behaviors, and hence by their expectations. Hence there are feedback paths from the true relationship to the individual expectations. A rational agent will be motivated to revise its expectations if it observes differences between expectations and experiences. An equilibrium of this system, in which the individual subjective distributions are identical to the true distributions, is called a rational expectations equilibrium (REE). The theory was extensively developed and applied in the 1970s and is now one of the standard approaches to both macro- and microeconomic analysis in the presence of uncertainty.

In a series of papers (Kobayashi 1993; Kobayashi 1994) and (Kobayashi and Tatano 1999) considered the application of the rational expectations approach to network problems, and particular to the analysis of route guidance systems. (Kobayashi 1993) develops an analysis of general networks of interacting agents (which he terms "logistical networks"). He extends the theory of games with incomplete information to include the formation of rational expectations under a Bayesian learning protocol, and characterizes and provides conditions for the existence of a rational expectations equilibrium. This paper provides a very simple example of REE in a traffic network.

These ideas are applied more directly to the analysis of traffic network route guidance systems in (Kobayashi 1994). Here the author considers a traffic network used by drivers with imperfect information about path travel times. Drivers receive guidance messages, which condition their expectations about path times. They then choose a path, and experience its true travel time; this may lead them to update their subjective expectations. Kobayashi shows that each driver's subjective expectations converge to rational expectations under mild conditions on the learning process.

In (Kobayashi and Tatano 1999) these ideas are further pursued. The authors use rational expectations theory as a basis for determining the welfare benefits of route guidance systems.

It should be pointed out that some authors have questioned the applicability of the rational expectations approach in a route guidance context. (Engelson 1997), for example, argues that the one-shot nature of incidents precludes drivers from forming a satisfactory internal model of the relationship between guidance messages and true network conditions in these situations.

Koppelman, F. S., and Pas, E. I. (1980). "Travel Choice Behavior: Models of Perceptions, Feelings, Preference and Choice." *Transportation Research Record*, 765, 26-33.

The intent of this study is to analyze and describe the consumer process of mode choice for non-work and non-school trips. The major objective of the research is to examine the relationships between consumers' perceptions, feelings and preferences as basis for understanding their mode choice behavior and for developing strategies to modify this behavior.

System characteristics serve as cues in the formation of consumers' perceptions of service characteristics. Each system characteristic is a partial indicator of one or more perceptions. The process of using system characteristics as cues to forming perceptions is called abstraction. Once perceptions are formed, they are aggregated to determine preference. Preference, modified by situational constraints such as mode availability, determines choice. Finally, experience gained by choice and behavior may feed back to modify perceptions.

Perceptions of transportation modes are measured by 24 attributes identified by review of the literature, qualitative research, and questionnaire pre-testing. Factor analysis is used to reduce these transportation service attributes to a smaller set of underlying cognitive dimensions. This provides a simpler perceptual structure that more closely approximates the consumers' use of information in decision making.

Feelings about modes are investigated to determine whether psychological or perceptual factors other than evaluations of mode performance influence transportation preference and choice. A variety of non-performance-related attitudes toward travel alternatives were measured (i.e. affects, personal beliefs, social beliefs). These measures are factor analyzed to develop an aggregate measure of feeling toward each mode.

Preference logit models are used to estimate the coefficients that relate perceptions and feelings to preferences. The estimated importance weights are used to compute a preference index for each individual for each mode. Multinomial logit choice models are used to estimate the influence of the preference index and a particular situational constraint (e.g. auto availability) in determining choice behavior. Estimation results of the preference logit and the multinomial logit models are presented.

Koutsopoulos, H. N. and T. Lotan (1989). Effectiveness of Motorist Information Systems in Reducing Traffic Congestion. Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS)**:** 275-281.

Hamerslag, R. and E. C. van Berkum (1991). "Effectiveness of Information Systems in Networks With and Without Congestion." Transportation Research Record **1306**: 14-21.

The article by (Koutsopoulos and Lotan 1989) describes an analysis of the congestion-reducing potential of ATIS. The authors develop a probit-based static stochastic user equilibrium (SUE) model of the Sudbury, Mass. traffic network. Two user classes are distinguished: informed and uninformed. They differ in the variability of their perceptions of link times, as determined by the (assumed) coefficient of variation (CV) (standard deviation divided by mean) of the utility error term. Informed drivers have a low perception CV, and hence perceive link travel times relatively accurately. Uninformed drivers have a CV of 50%, meaning that they have essentially no information on link travel times. These two classes are assigned to the network according using a stochastic assignment procedure, and the aggregate results (in terms, for example or total or average travel times) are obtained and used as measures of information system performance.

The authors carried out a number of experiments in which various system parameters were systematically modified. Modified parameters included: the amount of information {as reflected in the error term CV, ranging from 0% (perfect information) to 50%)}; the percentage of informed users; and the overall congestion level. The findings were generally in accord with what one would expect. There were moderate benefits from the introduction of traffic information. The percentage reduction in total travel time decreased monotonically between the case of no information (CV = 50%) and the perfectly informed case (CV = 0%), with lower percentage reductions overall at higher network congestion levels. The difference in average travel times between informed and uninformed drivers (measuring the value of the information to the informed drivers) decreased as the network congestion level increased; however, informed users always had much lower average travel times than uninformed users. With increasing percentages of informed users, the average travel time of both informed and uninformed users increased somewhat. Overall, however, the weighted average travel time decreased monotonically (but not always linearly) with increasing percentages of informed users.

(Hamerslag and van Berkum 1991) reports on a continuation and extension of the above work of (Koutsopoulos and Lotan 1989). They consider a variety of networks rather than the one considered above. Here, the travel time uncertainty impacts both route choice (as above) and destination choice. Destination choice is accounted for through a generalization of the gravity distribution model sensitive to perceived travel times. Fully informed drivers were modeled by the deterministic user equilibrium (DUE) principle, whereas less informed drivers were modeled by the SUE principle, as above. A combined equilibrium distribution-assignment model predicted the trip distributions and network traffic conditions that resulted from different levels of uncertainty and different network configurations.

It was found that in all cases the total vehicle-kilometers of travel (VKT) decreased with decreases in the level of travel time uncertainty, as the spatial distribution of trips adjusted to the changed perceptions. The authors conclude that information provision may reduce VKT by 15—20 percent in urban networks and by 5—10 percent in regional networks.

The authors note a number of limitations of their approach:

- information is seen as an abstract entity; it is not possible in this approach to represent and evaluation a specific information system or the effects of providing different types of information; and

- because it adopts a static equilibrium approach, the method is best suited to predict long-term effects of information provision in situations of recurrent congestion, rather than short-term dynamic effects of specific traffic phenomena such as incidents.

Koutsopoulos, H. N., and Yablonski, A. (1991). "Design Parameters of Advanced Driver Information Systems: The Case of Incident Congestion and Small Market Penetration." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 589-599.

The objective of this study is to examine the effects of design aspects of in-vehicle route guidance systems when used by a small number of participating vehicles (early stages of development with small market penetration). Such systems are also appropriate for the operation of emergency vehicles, commercial vehicles and other similar service systems.

The authors consider a relatively simple problem situation in which only a small number of vehicles receive guidance (hence the response of these vehicles to the guidance does not affect traffic conditions). Unguided vehicles do not change their behavior as a result of the actions of guided vehicles. Guidance consists of prescriptive expected minimum time path recommendations, which guided vehicles are assumed to comply with exactly. Traffic incidents introduce random variations in traffic conditions, which the guidance system generates messages in response to. Guidance may be received at the origin (before beginning a trip) or alternatively at various locations en route. Unguided drivers, or guided drivers before they receive the first message, make routing decisions based on typical ("historical") travel times.

A traffic simulation model was developed to investigate guidance system design parameters in this situation. The model simulates the movement of a single vehicle traveling through the network and interacting with other vehicles. All events which may occur are modeled probabilistically. When the vehicle arrives at an information source it determines a new shortest path to its destination based on the provided travel time information. Randomly generated incidents reduce link capacity (through lane blockage and also "rubber-necking") and may lead to queuing; important incident characteristics include its severity, duration and time required for normal flow conditions to be re-established after the incident is cleared.

System parameters of interest are:

- the frequency of information updating: a range of intervals is evaluated, from immediate notification upon the occurrence of an incident, to updating only after a predetermined amount of time has passed

- location of information sources: from no information (guidance is based on pre-trip historical information) to an ubiquitous system in which information updates are available at all intersections in the network; and

- level of intelligence: a lower level uses current information and assumes that it remains valid for the duration of the trip; average queue delays are used to compute travel times on links with incidents. A higher level is based on expected queue clearance time, and takes into account link times at the time a vehicle is expected to arrive at the link.

To evaluate the effects of these design parameters on system performance, the model was applied to the (moderately congested) Sudbury, Massachusetts network, using data on incident characteristics from a nationwide study.

The results from a case study indicate that there are significant trade-offs among the design parameters. For example, when guidance is ubiquitous (available at all nodes), both the frequency of update and the level of intelligence of the guidance messages become relatively less important. Furthermore, benefits to equipped vehicles due to the availability of information on traffic conditions were small with respect to average travel time reductions but significant with respect to improvements in travel time reliability. Use of accurately forecast link times as the basis for guidance was seen to be an important determinant of the benefits resulting from guidance. The results also indicate that improved incident management (if possible) with reduced response times could also be very effective in reducing the effects of accidents, especially when combined with advanced traffic information systems.

Kratofil, J. A., Jr. (2001). A Benefit-Cost Analysis for the Use of Intelligent Transportation Systems Technology for Temporary Construction Zone Traffic Management on the I-496 Reconstruction in Lansing, Michigan. Master of Science in Administration, Central Michigan University.

This relatively brief paper presents an investigation into the costs and benefits of applying real-time ATIS technology to construction zone traffic management (CZTM) on the I-496 reconstruction project in Michigan. It notes that only a handful of ATIS implementations have been carried out for the purpose of temporary CZTM in the U.S. One of the merits of the paper is that it presents a review of the (relatively small) literature on the benefits and costs associated with this application of ATIS technology to this particular application. Another merit is that it proposes a methodology for quantifying some of the likely benefits of this application, utilizing more-or-less standard ITS evaluation frameworks but specializing the concepts and the relationships for application to CZTM.

The evaluation framework adopted by the author includes the standard evaluation areas of mobility, efficiency, safety, productivity, energy/environment and user satisfaction; and distinguishes impacts in terms of their incidence on drivers, the agency (MDOT) and the surrounding community. In this application, development of specific measures in each of these areas must recognize the temporary, short-term nature of CZTM. In comparing construction zone conditions with and without ATIS, the author proposes to measure the benefits of the ATIS in terms of reductions in accidents with injuries and fatalities, reductions in travel time delays, improvements in throughput, improvements in customer satisfaction, and reductions in emissions and fuel consumption. Quantities for the no-ATIS case are derived from historical data and standard values. Quantities for the ATIS case are estimated based on results reported in the ATIS literature (although not usually obtained from studies of construction zone situations).

On carrying out the benefit/cost calculation, the report concludes that, overall, the application of ATIS technology to provide real-time information to drivers in the I-496 construction zone would have a benefit/cost ratio of approximately 2. It recommends monitoring traffic conditions during the reconstruction project in order to check the validity of the assumptions made for the benefits calculation. It further recognizes that there may be additional benefits resulting from the presence of ATIS that could not be quantified, and recommends that MDOT conduct surveys to gather data on customer satisfaction with ATIS, and more particularly on users' valuation of the benefits they receive from such systems.

Lee, J., Douglass B. "Benefit-Cost Evaluation of Traveler Information: Seattle's WSDOT Web-site." *Transportation Research Board 79th Annual Meeting*.

The Washington State DOT Northwest Region freeway management system (FLOW) provides a variety of travel-related information via the Internet, including information about construction projects, road closures and ferry service. The primary information content is real-time (dynamic) information about prevailing traffic conditions on expressways and major arterials, displayed by lane and roadway segment, using a color-coded system; condition data is updated every two minutes.

This paper presents a framework for the benefit-cost evaluation of the FLOW system and applies it to evaluate the year-1999 capabilities of the FLOW system. It uses what (little) data is available (mostly from wave 7 of the PSRC and from the MMDI), supplemented with assumed parameter values, to estimate the economic benefits resulting from particular types of impact to particular types of travelers. It sums these to get total FLOW benefits, and compares with a rough estimate of costs. The specific conclusions reached are perhaps not reliable, given the many assumptions that were required in reaching them; the value of the paper is in providing the evaluation framework and in indicating the types of data that would have to be collected in order to reach more reliable conclusions.

The framework distinguishes five market segments in terms of their trip purpose and likely information needs and behavior response: commuters; business travelers familiar with the area; business travelers unfamiliar with the area; people on shopping or personal trips; and tourists. It categorizes people as auto users, transit users or choice users (non-captive to a particular mode).

The responses to information that are considered are: change mode; add trip; delete trip; change destination; change route; change departure time; change confidence level; and nothing.

Impacts are characterized as internal (to the traveler), and external (to other travelers and the outside world), with further breakdown in each category.

Evaluation of internal impacts depends on whether the impact (information response) is directly related to travel time saving (for example a route change) or not. In the former case, the time savings are estimates and converted into monetary equivalents based on standard values of time. Different travel conditions give rise to different unit values of time: since time spent traveling is more onerous in congested conditions than in other “serene” conditions, it is valued more highly. Consequently, there is a benefit associated with a change that results in the same amount of time being spent “serenely” rather than irritated in congestion.

If an information response is too complex to be tied directly to a travel time saving, then the framework suggests evaluating it via the resulting change in consumer's surplus, meaning the traveler's willingness to pay to get the information that would allow the (particular decision to be made), as determined for example from stated preference surveys. These were not carried out however.

In general, an information response entails a range of impacts, each of which is quantified appropriately. For example, a route change produces travel time changes, changes in social costs, changes in VMT, and a change in the amount of time spent "serenely".   A change in mode produces similar impacts as well as consumer surplus changes. Travelers who receive relevant information but choose to travel in the way they would have without receiving the information are assumed to benefit from increased confidence in their decision. A change in confidence level changes the amount of time spent "serenely" instead of irritated.

The report estimates the unit internal benefits from the considered responses to information. Interestingly, it concludes that changes in destination result in large internal benefits, even though they are relatively rare. Changes in route and departure time, generally considered more common, are less beneficial.

External impacts are computed as the difference between marginal and average costs. Changes in modal VMT are used to compute external emissions costs, while changes in travel time are used to compute external congestion costs.

FLOW system costs were difficult to estimate because components of the system had been created over time and later integrated into FLOW. It was also difficult to separate out the particular costs appropriate for the evaluation. Broad estimates had to be made.

The framework was applied to the FLOW system, assuming that usage will increase considerably after two years of operation (Phase II) and remain constant thereafter. The analysis estimated that current (Phase I) net benefits from FLOW were negative, turning positive in Phase II. The overall benefit/cost ratio was estimated as 2.0, with a range of uncertainty between 0.5 and 3.0. Under the assumptions presented above, the project looks worthwhile, but the report notes that there is little evidence of actual impacts and even less for their valuation.

The report concludes that properly focused data collection could greatly reduce the range of uncertainty in ATIS benefit-cost evaluations.

Llaneras, R. E., and Lerner, N. D. (2000). "The Effects of ATIS on Driver Decision Making." *ITS Quarterly*, 8(3), 53-63.

The authors investigated the effects of en route ATIS messages on driver behavior using a real-time travel choice simulator. The objective was to determine how en route driver decision making changes based on the type of real-time ATIS messages provided (no ATIS, basic ATIS and enhanced ATIS), and the prevailing traffic conditions (light (LOS A) and moderately heavy (LOS D)) within the visual range of the driver.

Basic ATIS provided descriptive information on accidents and congestion, including notification of an incident (including type and location) or congestion, and estimated delay expressed in qualitative terms. Enhanced ATIS included all the information available in the basic level, plus options to obtain information on alternative routes, on incident details, access to a real-time traffic condition map, and access to live video traffic images.

A network of Washington, D.C. freeways and surface streets was simulated. Seventy-two drivers, relatively familiar with the network and ranging in age from 18 to 86 years, took part in the study. Subjects were asked to drive, starting at 2:30 p.m., from a location in Rockville MD to a location on the campus of the University of Maryland for an appointment at 3:15 p.m. These trips were fully under the control of the driver in terms of route selection and were experienced in real-time under realistic time pressures. Prior to starting, subjects were allowed to study a map of the network, and were asked to mark their intended route on the map. Four incidents were programmed into the network, and the design was such that a driver could save 20% or more of remaining trip time by switching to alternate routes that bypassed the delays.

The following conclusions were drawn:

- basic ATIS results in substantial diversion, but drivers desire and use additional information if available;

- additional information increases diversion rates and improves alternate route choice. Although access to enhanced information does not prevent poor alternative routes from being selected on occasion, the losses that do occur tend to be small compared to those that can occur with basic ATIS services;

- poor choices of alternate routes were common with basic ATIS;

- the most desired and effective types of information include: incident location; incident type; estimated delay associated with incidents; length of backed up queue; suggested alternate routes; and alternate route directions. Traffic map information containing incident locations and estimated link travel times was highly desired;

- integrated information appears to be preferred and enhances information extraction. The traffic condition map was the most frequently access information option. Information should be communicated in a directly usable form; and

- the human factors question of how best to present and display various forms of information remains open.

Lyons, G., R. Harman, J. Austin and A. Duff (2001). *Traveller Information Systems Research: A Review and Recommendations for Transport Direct*, Transportation Research Group, Department of Transport, Local Government and Regions, U.K.

Transport Direct is an ambitious program to create and operate a travel information service that will allow travelers in the U.K. to compare travel options across the full range of public and private modes. It seeks to provide, in a single point of contact, journey planning, booking and payment services, and real-time trip status information updates.

As part of the preparatory activities for Transport Direct, the U.K. DTLR commissioned a comprehensive review of previous, current and planned research in areas of relevance to Transport Direct. The present document summarizes the conclusions reached from the review. It covers a wide range of technological, institutional, marketing, and usage factors, grouped into 13 topic areas, both discussing current knowledge in the area and recommending further actions required for the implementation of Transport Direct. The discussion is at a fairly high level and almost always oriented to the specific needs of the planning and implementation of Transport Direct.

Of particular interest here are conclusions in the areas of consumer demand for information; information requirements of the end user; the importance of awareness and marketing; the effects of information on behavior; the willingness to pay for information; and the integration of real-time data and data collection systems into travel information systems.

The conclusions are presented in a condensed summary form, and so are difficult to summarize further here.

Madanat, S. M., Yang, C. Y. D., and Yen, Y.-M. (1995). "Analysis of Stated Route Diversion Intentions Under Advanced Traveler Information Systems Using Latent Variable Modeling." *Transportation Research Record*, 1485, 10-17.

This paper describes an analysis of the factors that explain drivers' route diversion behaviors using latent variable modeling methods. The analysis focuses particularly on drivers' attitudes towards diversion, and on their perception of the reliability of radio traffic reports and variable message signs as latent explanatory variables.

A stated preference survey of commuters on I-94 in Indiana was carried out. Respondents were asked about their socio-economic characteristics and the characteristics of their commute trips. They were also presented with a series of statements reflective of different possible attitudes towards route diversion and perceptions of the reliability of traffic information provided by radio traffic reports and variable message signs, and asked to indicate their degree of agreement or disagreement with these statements. In addition, they were presented with hypothetical situations involving congestion and different types of ATIS messages (qualitative descriptive, quantitative descriptive with different types of information, prescriptive) and asked whether they would divert or not.

Two different techniques were used to analyze this data.

First, a LISREL latent variable model was specified and estimated. The specification hypothesized two latent factors: drivers' general attitudes towards route diversion, and drivers' perceptions of the reliability of traffic information, which is assumed to affect their attitudes towards diversion. The indicators of these latent factors were simply the drivers' responses to the attitudinal questions. The results of the LISREL model estimation show significant and reasonable loadings of responses to the attitudinal questions on the latent factors, and also show a significant influence of information reliability perception on attitude towards diversion.

Next, binary logit models of path switch probability were estimated from the responses to the hypothetical diversion questions. Independent variables included an indicator of the types of information provided; descriptors of travel and socio-economic characteristics of respondents; and the respondent's latent variable values, obtained from the estimation results of the LISREL model. (Because of the nonlinearity of the logit form, this sequential estimation procedure is not only inefficient but could also lead to inconsistent estimation results. Consistency requires that the latent variable and binary logit diversion models be estimated simultaneously, but this was not done.) In general, the estimation results showed increasing probability of diversion with increasing level of information detail. Prescriptive guidance was found to induce the highest diversion rate. Young and unmarried drivers were more likely to divert, as are those with positive attitudes towards diversion and confidence in the reliability of radio traffic reports and variable messages signs.

Mahmassani, H. S., and Chang, G.-L. (1985). "Dynamic Aspects of Departure-Time Choice Behavior in a Commuting System: Theoretical Framework and Experimental Analysis." *Transportation Research Record*, 1037, 88-101.

Mahmassani, H. S., and Chang, G.-L. (1986). "Experiments with Departure Time Choice Dynamics of Urban Commuters." *Transportation Research B*, 20B(4), 297-320.

Mahmassani, H. S., and Stephan, D. G. (1988). "Experimental Investigation of Route and Departure Time Choice Dynamics of Urban Commuters." *Transportation Research Record*, 1203, 69-84.

These papers address the day-to-day dynamics of departure time decisions of urban commuters and the underlying behavioral mechanisms determining user responses to dynamically varying time-dependent congestion patterns.

In (Mahmassani and Chang 1985), the behavior of actual commuters is observed under controlled conditions. Participants, facing a hypothetical though realistic commuting situation, supply daily departure time choices in response to congestion conditions, which are in turn obtained by using a special purpose traffic simulation model, given the time varying demand pattern. In this paper, the results of such an experiment, involving 100 participants over 24 days, are examined from the perspective of the processes governing the dynamics of the users' behavior.

User behavior can be viewed as a boundedly-rational search for a satisfactory departure time. Conceptually, it consists of two principal components: 1) the acceptance or rejection of a given day's decision outcome, which determines, respectively, whether the user will or will not maintain the same departure time on the following day and 2) the amount by which departure time should be adjusted, if that is needed. The first component can be viewed as the stopping criterion in the user's search process, whereas the second is analogous to the 'step size'. The former is based on the key notion of an indifference band of tolerable schedule delay. Prior experience with the facility, as the principal mechanism of information acquisition, enters the first component through its effect on the indifference band, and the second component through its contribution to the user's learning about the facility's performance. The use of schedule delay as the principal criterion for acceptability of a given decision outcome should not be taken to imply that other attributes, particularly travel time, will under no circumstances be explicitly evaluated by trip makers. However, in an urban commuting context, particularly for short range, day-to-day decisions, schedule delay is clearly significantly more highly valued (negatively) than travel time.

The approach for obtaining adequate data for the study of day-to-day dynamics of commuter behavior consists of observing the decisions of real commuters placed in controlled and carefully designed hypothetical commuting situations. The commuting context considered in this experiment consists of an urban corridor composed of a four lane highway used by residents who live adjacent to it for their daily home-to-work trips to a single work destination. At the onset of the experiment, each participant was asked to state his/her preferred arrival time at work, in the absence of traffic congestion, given the official work start time. Every simulation day, each participant supplied a departure time and an anticipated travel time. The departure time decisions of all individuals in a given sector were aggregated into a time-dependent departure pattern for that sector. These patterns form the input to the highway traffic flow simulation model. A special purpose, fixed-step macroscopic highway simulation model was developed in conjunction with this experiment. The highway facility is segmented into number of sections, in which traffic flow is modeled by using well-established fundamental traffic flow relationship. The outcome of each participant's decision and the corresponding travel time were determined by the simulation and supplied to each participant individually on the following day before that day's choice. This iterative interactive process covered 24 simulation days, by the end of which the system had evolved to a stable state, with all participants maintaining the same choices from one day to the next.

The results reveal that over 40 percent prefer to reach their workplace at least 15 minute before the official work start time. The distribution of the preferred arrival time is primarily a reflection of inherent differences in individual preferences and does not exhibit any systematic variation across sectors. The frequency of the proportion of participants in each sector who changes their daily departure time at least n (n=1,2,…,15) times increases with distance from destination, thus confirming the observation that more distant sectors experience greater difficulty in converging to a steady state. The fraction of users who find a particular schedule delay unacceptable and thus change departure time on their next day increases with the magnitude of the delay. More distant users ultimately accept larger schedule delays and as such possess wider indifference bands of tolerable schedule delay.

(Mahmassani and Chang 1986) is very similar to (Mahmassani and Chang 1985) (discussed above) in 1) the explicit treatment of the day-to-day dynamics of departure time decisions, 2) the specifications of mechanisms by which individual users adjust their decisions on a daily basis, given prior experience, 3) the boundedly-rational heuristics that are assumed to govern individual tripmakers' behavior, and their use in a modeling framework that recognizes the interaction between user behavior and system performance, and 4) the use of a special-purpose traffic simulation model to study the dynamics of user behavior.

An interesting result obtained in this paper is that of the interrelation between the tolerable schedule delay and the demand level in determining the properties of the system. Convergence to the steady state constitutes the type of behavior that one would expect in a commuting corridor, with users following an essentially stable routine. However, the non-converging situation is not an unrealistic one, particularly if the system involves users who are not familiar with the facility, or a system ‘in learning’. The key results are that (a) under a given demand level, users must be willing to accept a certain amount of schedule delay as the price for a certain degree of reliability in their arrival at the workplace, and (b) more distant users need to have a wider indifference band. The decision process followed by users would then consist of adjusting one’s indifference band in order to allow for a routine commuting pattern. This adjustment would take place in response to learning from one’s repeated experience and outside information source.

The system at steady state can be viewed as being in equilibrium, in that no user has an incentive to change departure times, because each user is satisfied that his schedule delay is within the tolerable limit. Such an equilibrium does not correspond to the more familiar user equilibrium and its extension to the time-dependent departure problem. Furthermore, a steady state of the type reached in this study is not unique for a given system of users and facilities, but is highly dependent upon the initial informational conditions of the users. Boundedly-rational user behavior is likely to result in multiple solutions that satisfy a particular population of users, none of whom is seeking an optimum, but merely an acceptable solution.

(Mahmassani and Stephan 1988) extends the work conducted in the two papers discussed above in two directions: 1) the inclusion of the route choice dimension in addition to that of departure time and 2) the consideration of two user groups with different information availability levels interacting in the same simulated commuting system.

The effect of information availability on the behavior and performance of given user groups is of particular interest. In this regard, the results of this experiment are to a large extent consistent with a priori expectations based on intuition; that is, users with more information clearly outperform those with limited information when both are competing in the same system. The fraction of total users with particular information levels, however, appears to be a significant determinant of the effect of this information. In the limit, if all users share the same complete or limited information, a system with complete information may experience greater turbulence in its evolution.

Interdependence between route choice and departure time decisions is another important aspect of user behavior addressed in this paper. The exploratory aggregate analysis considered here points to the precedence of departure time shifts over route shifting in dealing with experienced unpredicted congestion in the system. The explanation for the observed behavior within the previously articulated boundedly rational decision framework appears to be plausible, and preliminary results of model estimation work are confirming this explanation. The insights based on these exploratory analyses from the principal hypotheses guiding the development and calibration of dynamic discrete choice models of user behavior.

Mahmassani, H. S., Hatcher, S. G., and Caplice, C. G. "Daily Variation of Trip Chaining, Scheduling and Path Selection Behaviour of Work Commuters." *6th International Conference on Travel Behavior*, Quebec City, Canada, 351-379.

This paper addresses the day-to-day variation of three key aspects of the home-to-work commute: 1) the time of departure from home, 2) the frequency, purpose, and duration of intervening stops between home and work, and 3) the path actually followed through the network. It is based on two-week detailed diaries of actual commuting trips completed by a sample of auto commuters in Austin, Texas. This study addresses the daily variation of trip-chaining behavior of commuters, and relates it to various attributes of the commuter, the workplace, and the commute.

A two-phase mail survey was conducted in Spring, 1989, to collect data from commuters residing in the Northwest section of Austin, Texas. For the purpose of this study, the trip represented by morning commute is referred to simply as trip chain. Because only before-work paths are considered in this paper, all trips begin at home and end at work. These trips may or may not have intermediate stops. Diary information available for each stop includes the location, purpose, arrival time and departure time. For each commuter, a stops ratio was calculated by dividing the number of trips with stops by the total number of trips reported by that commuter.

Insights into the factors that influence trip-chaining behavior in connection with the morning commute would contribute to the ability to develop and analyze demand-management policies. For this purpose, a Poisson regression model of the number of daily stops made by commuters was used. This distribution is particularly appropriate because the dependent variable naturally assumes only non-negative integer outcomes, including a relatively large number of commuters with zero stops (a problem that makes OLS regression biased). A Poisson regression model was derived for different numbers of observed days per commuter to eliminate the problem of unequal number of days for participants in the travel diary (standard Poisson regression applications assume an equal number of trials).

Critical to the modeling of commuter behavior in transportation systems are the mechanisms by which users choose routes and departure times, and the factors that determine the variability of these decisions from day to day. This study analyzed the departure times and street paths taken by each commuter for the journey to work over the two week survey period. Two ways of capturing departure time switching behavior are discussed in the study: 1) switching from a commuter's median departure time (median switching), and 2) switching from a user's previous day's departure time (day-to-day switching). The former is intended to capture deviations from a usual daily routine. The median was chosen for this purpose, instead of mean, to avoid the undue influence of outliers in a commuter diary. By the day-to-day definition, the current day is considered a switch from a previous day if the absolute difference from their respective departure time exceeds (or meets) some minimum threshold. Two definitions of route switch were also explored. First, the paper defines a mode-route switch as a deviation from the normal or mode (most frequently used) network route, in which the commuter follows a different from usual set of nodes to arrive at work. This criterion recognizes the observed dominance of one route over all others for most commuters. Second, it defines a day-to-day route switch when the chosen route is different from the previous day's route.

A commuter needing to make a non-routine stop(s) on the way to work will generally incur the stop duration(s) and the stop-induced extra travel time. Accordingly, the commuter may decide to shift departure time at home, arrival time at work, or both. With respect to route choice, users may have to deviate from their mode route in order to make a non-routine stop(s). This paper addresses the impact of trip chaining on departure time and route switching behavior in two ways. First, it tests whether trips with stops are more likely to be switches. Second, it tests the explanatory power of the stops ratio in the daily switching models. To perform the first test, a chi-squared statistic was computed for the hypothesis that the presence of a stop on a given commute is independent of whether that trip is a switch. Poisson regression models are developed to investigate the effect of the characteristics of the commuter and of the commuter environment on the frequencies of departure time, route and joint switching respectively. The stops ratio is used as an explanatory variable in the model specification. Daily-frequency models are estimated to account for varying numbers of trips across commuters. Several workplace characteristics are important in the model. Several commuters and commute related attributes are also significant in the departure time switching model.

About 25 percent of all reported commutes contained at least one non-work stop, underscoring the importance of trip-linking in commuting behavior. These multipurpose trips are shown to influence significantly the departure time and route-switching behavior of commuters. The stops ratio and commuting trip time variability are important determinants in all reported switching models. Workplace and commuter-preference variables such as lateness tolerance and preferred arrival time otherwise dominate the departure time and joint-switching behavior. Socioeconomic variables such ac gender, age and interaction variables containing gender also display explanatory power, but their effect is not as clear cut. Other personal and household characteristics may be important, but human behavioral considerations may obscure forming theoretical expectations for their impact.

Mahmassani, H. S., Huynh, N., Srinivasan, K., and Kraan, M. "Tripmaker Choice Behavior for Shopping Trips Under Real-time Information: Model Formulation and Results of Stated-Preference Internet-Based Interactive Experiments." *Transportation Research Board 80th Annual Meeting*.

Kraan, M., Mahmassani, H. S., and Huynh, N. "Interactive Survey Approach to Study Traveler Responses to ATIS for Shopping Trips." *Transportation Research Board 79th Annual Meeting*.

The objective of these research efforts is to study the behavioral responses of travelers under real-time information during non-commute trips, particularly shopping trips. Behavioral responses of interest involve en-route diversion to alternate destinations and alternate routes. An interactive stated preference survey, accessible through the Internet, was designed and conducted to study the role of information on shopping trip decision-making. The survey consisted of three parts. The first part seeks information on personal characteristics and familiarity with the Austin area and the shopping centers. The second part asks respondents to make a shopping trip starting from a location in the center of Austin, Texas to one of the major shopping centers in the area. This part requires the subject to respond to a sequence of events, which involve selection of shopping centers and routes. Different pre-trip and en-route information items are provided to respondents in the course of the decision making process. The survey concludes with a questionnaire on preferences toward traveler information systems and factors affecting the choice of the shopping destination.

The nature of the dynamic decision context is such that ATIS information is progressively revealed to the traveler. The complete choice set (destination and route) is not presented at the time when the tripmaker is asked to make a decision, and information regarding each alternative is provided only when needed. During the course of the interactive survey, participants received information according to their decision state, which depended on prior choices and unfolding exogenous events. Following a change in traffic conditions while en-route to one destination, participants are asked whether they would like to change to another destination. If they decide to continue with the same destination, they are then provided with additional information on route choice. On the other hand, if they decide to change destination, they are then given trip time on the best route to alternative destinations. Hence, the route switching query is only appropriate if the destination remains the same. Switching destinations implies a switch of route, given the relative locations of the alternate malls.

For the sequence of switching decisions faced by the tripmaker, the following three alternative outcomes are possible: 1) no switching, 2) switch route (going to the same destination), and 3) switch destination. As noted, the latter decision implies a switch of route as well. The nesting associated with the structure is a direct manifestation of the survey design. To model this problem, a framework is developed to capture the conditional nature of the choices. By inspection, this is a bi-level decision process with two decision states. The first involves the decision to switch mall or not and the second involves the decision to switch route or not. The respective binary choice models are presented using random utility theory terminology. Explanatory variables considered include both decision maker attributes and transportation system attributes. Individual attributes include socio-demographic characteristics such as age, gender, educational background, occupation, and familiarity with the network and the shopping centers. Transportation system attributes include travel time and cause of congestion, which are conveyed to travelers through ATIS. The developed model provides information about en-route diversions during shopping trips, and on factors affecting these decisions, especially with regard to the role of real-time information.

The results indicate that gender, age, level of education and high income are not statistically significant in explaining either route or destination switching. Those respondents who are not familiar with Austin, defined as those who lived in Austin for less than a year, are more apt to switch destination, but not route. Those who visit the same mall on a frequent basis are less likely to switch route and destination. Finally, it is found that tripmakers do switch routes and even destinations when presented with delay information.

The model also accounts for heteroscedasticity and correlation between the decision states and trip dimensions. While the data suggests that there is no difference in variances in the error terms, with respect to the first choice, there exists correlation among the decision states and along the trip dimensions. The inclusion of such correlation improves the model.

An interesting implication that arises from this study is the method by which ATIS disseminates information to users. Information can be presented all at once or partially and progressively, with obvious tradeoffs in either case. The advantage of presenting everything all at once is that users can make a more informed decision. The disadvantage is that providing too much data could make it difficult for users to process and analyze it. Information overlap can limit the effectiveness of such information. On the other hand, the advantage of presenting information partially is that it will be easier for users to process the presented information. The disadvantage is that users may have opted to choose differently had they known ahead of time about other choices.

Mahmassani, H. S., and Jayakrishnan, R. (1991). "System Performance and User Response Under Real-Time Information in a Congested Traffic Corridor." *Transportation Research A*, 25A(5), 293-207.

Mahmassani, H. S., and Peeta, S. (1993). "Network Performance Under System Optimal and User Equilibrium Dynamic Assignments: Implications for Advanced Travel Information Systems." *Transportation Research Record*, 1408, 83-93.

These articles are among those that describe the development of the DYNASMART (Dynamic Network Assignment Simulation Model for Advanced Road Telematics) simulation system by a team at the University of Texas at Austin.

DYNASMART is a mesoscopic traffic model, meaning that it processes individual vehicles using macroscopic traffic relationships. (It is also able in principle to process small groups of vehicles called packets as a unit, but in practice the "packets" usually consist of single vehicles.) In general terms, DYNASMART:

- represents drivers' path choice and path switching decisions in a network;
- moves vehicles along paths, accounting for traffic congestion effects; and
- implements logic that computes dynamic user optimal (DUO) or approximate dynamic system optimal (DSO) flow patterns in accordance with driver behavior and vehicle movement components.

Path choice decisions are based on dynamic (i.e. time-varying) travel times. DYNASMART allows for several user classes based on route choice criteria. One "background" class is assigned to paths based on a default criterion, and do not revise their decisions thereafter. Some form of minimum time criterion is generally used for the other classes. One class is assumed to follow paths having minimum instantaneous travel times. Another class is assumed to follow DSO routing: drivers are assigned to paths having minimum marginal travel time, where the marginal effects are estimated using a heuristic. Another class is assumed to follow DUO routing, in which drivers are assigned to minimum experienced time paths. However, for this class en route path switching decisions in response to guidance updates from information sources at nodes are also incorporated using a form of bounded rationality. Specifically, drivers will not switch from their current (sub-optimal) path to the true minimum time path if the time savings do not exceed a certain minimum indifference band. When the savings do exceed the indifference band, drivers switch with a probability that increases with the relative magnitude of the savings. DYNASMART maintains a "working" set of explicitly-represented paths that it updates periodically.

Vehicles are moved along links at the prevailing local speeds, consistent with a relationship between average speed and the prevailing vehicle concentration on the link; a modified Greenshields model is used for this purpose. The simulation is time-based, with a fixed time step on the order of 0.1 minutes. In each time step, vehicles are moved at the prevailing local speed along their link, or are transferred to the next link on their selected path. Vehicle concentrations are updated and the corresponding average speeds are computed for the next time step. Vehicles can only transfer to a downstream link if sufficient storage capacity is available there; lacking that, queues will develop, and add to vehicle traversal times.

Solution control logic in DYNASMART is similar to the method proposed by Sheffi and Powell for solving static stochastic user equilibrium problems. It is an iterative method where, to compute the solution estimate in iteration k, the solution estimate from iteration k-1 is updated by a weighted combination with an "auxiliary" solution obtained from an all-or-nothing traffic loading based on the travel times from iteration k-1. The weight used is equal to 1/k. (This is known as the method of successive averages, or MSA.) In the case of DYNASMART, the variables involved in the solution process are path flows by origin, destination, departure time from the origin and path.

Mannering, F. L. (1989). "Poisson Analysis of Commuter Flexibility in Changing Routes and Departure Times." *Transportation Research B*, 23B(1), 53-60.

Jou, R.-C., and Mahmassani, H. S. (1994). "Comparability and Transferability of Commuter Behavior Characteristics Between Cities: Departure Time and Route-Switching Decisions." *Transportation Research Record*, 1556, 119-130.

The Mannering paper deals with the development and estimation of a route and a departure time choice model for the morning commute to work. The approach focuses on the frequency of route and departure time changes, and relates such changes to factors that influence travel information needs.

A survey of morning work trip commuters was conducted in the Seattle, Washington area with the specific objective of gathering information on the frequency of commuters' route and departure time changes. The survey was conducted in May 1987 and focused primarily on commuters going from suburban communities to Seattle work locations. In terms of the frequency route and departure time changes, information was gathered on the average number of times that commuters change routes and departure time per month. In all, 117 commuters were surveyed by telephone.

Two models were developed – one representing the number of route changes per month and the other representing the number of departure time changes per month. Central to the modeling analysis is the behavioral assertion that, due to factors such as commuters' continual experimentation, as well as random effects including vehicle breakdowns, accidents and weather conditions, commuters will never completely settle on a fixed route and departure time. Within this context, a Poisson distribution is found to be a reasonable description of the number of route and departure time changes occurring during a one-month period. Such a methodological approach is commonly referred to as Poisson regression. Poisson regressions of the number of route and departure time changes per month were estimated.

The route change model results indicate that all variables are of plausible sign and reasonably high statistical significance. It was found that the travel time of the most frequently used route has a positive impact on the average number of route changes per month, indicating that longer commutes make travelers more likely to change routes. The average level-of-service of the most frequently used route also had a significant positive effect, indicating that travelers normally commuting on congested routes tend to make more route changes per month. Estimated additional trip travel time on the shortest time alternate route also proved to be a significant variable. It was also found that as commuters' age increases fewer changes were made.

Estimation results of the departure time change model indicate that higher travel times on the most frequently used route make a commuter more likely to change departure times. The variable indicating if the commuter has a flexible work start time is properly signed but statistically insignificant. The socio-economic variable of age and marital status produced results similar to those of the route change Poisson model.

Elasticities of the average number of changes per month with respect to the model's independent variables were also calculated. For the route change model, the number of changes was inelastic with respect to all variables except the additional trip travel time on the shortest time alternate route. Departure time choice is elastic with respect to commuters' age but inelastic with respect to travel time.

The paper by Jou and Mahmassani is very similar in methodology to the one by Mannering except that the data used were obtained from a different location and the survey methodology was different. A two-stage survey was conducted in the Dallas and Austin area in Texas. The first stage was a mail back questionnaire survey and the second stage was in the form of travel diary of respondents for two weeks.

Mannering, F. L. (1997). "Modeling Driver Decision Making: A Review of Methodological Alternatives." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 187-216.

The objective of this chapter is to review methodological alternatives for modeling driver decision making, and to give examples of how driver decisions particularly relevant to ITS can be approached. The methodological techniques chosen for presentations all have the capability of being integrated into a more general predictive model of urban traffic flow. Thus, the focus of this chapter is not just on the analysis of driver decision making, but also on the prediction of driver decision making in the presence of a changing environment of technology and information.

This chapter overviews a wide variety of modeling techniques that can be used to handle the types of data likely to be encountered in modeling driver decision making. The types of data include : count data, continuous-continuous data, discrete data, discrete-continuous data, duration data and ordered data. The techniques in this chapter are very useful tools for analyzing driver decision making. The intent of this chapter is to give the reader a basic understanding of the various modeling approaches along with some of the likely pitfalls that may be encountered. It discusses the importance of selecting a methodology suited to the decision making process being modeled, and of carefully searching for possible model specification errors. Useful references are provided for all the methods discussed in the chapter.

Different computer software packages available for estimation of these modeling techniques are mentioned. The advantages and disadvantages of each are also discussed.

McDonald, M., Hounsell, N. B., and Njoze, S. R. (1995). "Strategies for Route Guidance Systems Taking Account of Driver Response." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 328-333.

This paper describes RGCONTRAM, a version of the CONTRAM5 traffic model that was enhanced to incorporate route guidance and driver response to it. RGCONTRAM was developed at Southampton University in collaboration with the University of Leeds (both in the UK).

RGCONTRAM is a mesoscopic traffic model: it represents individual vehicles or vehicle "packets" but moves them according to aggregate speed-flow relationships. It distinguishes between "guided" vehicles, which have access to real-time traffic information from a traffic guidance center; and "unguided" vehicles, which do not. As guided vehicles move through the network, they transmit to the guidance center their travel times on recently-traversed links. The center uses this information to update historical traversal time profiles maintained for each link. The center then forecasts travel times on different links over a medium-term time horizon (for example, one hour). It computes shortest time paths based on this, and transmits back to the vehicles the recommended path. Drivers may then choose to divert based on this recommendation. The model incorporates different guidance response behaviors that depend on drivers' familiarity with the network. There is parallel logic for familiar and unfamiliar unguided drivers. Various parameters control factors such as the degree of accuracy of drivers' link traversal time perceptions; the willingness of familiar drivers to accept guidance recommendations, and the path time difference threshold below which route choice is not reconsidered. RGCONTRAM developers have attempted to estimate these parameters in part through survey work, but the estimation results are not provided in this paper.

RGCONTRAM can run in either of two basic modes. In single day (SD) mode, it is basically a dynamic network loader which incorporates route choice and route diversion logic dependent on information. Alternatively, it can operate as an information-sensitive dynamic traffic assignment model to compute a dynamic user-optimal equilibrium flow pattern. SD mode is appropriate, for example, for predicting traffic conditions resulting from a one-time incident situation, while the dynamic equilibrium mode is more suitable for determining traffic conditions resulting from the long-term operation of a route guidance system under normal traffic conditions.

Mehndiratta, S. R., Kemp, M., Lappin, J., and Brand, D. (1999). "What Advanced Traveler Information System Information Do Users Want? Evidence from In-Vehicle Navigation Device Users." *Transportation Research Record*, 1679, 41-49.

Kemp, M., and Lappin, J. (1999). "Need to Know." *ITS International*, 21, 57-58.

These papers report findings from research into private vehicle user preferences for ATIS services. The research is based on surveys of users of dynamic in-vehicle navigation systems in Seattle (the SWIFT operational test), Chicago (the ADVANCE operational test) and Boston (a private test by SmartRoute systems, Siemens automotive and NYNEX cellular). The units receive real-time information about traffic conditions and can utilize that information to provide navigational assistance to the driver.

The authors first conducted qualitative research into user reactions to various ATIS product concepts. They then prepared stated preference surveys of people who had used the in-vehicle systems for a significant time as part of field operational tests. In the survey, respondents were asked to assume that their next vehicle would be equipped with similar hardware, then were asked trade-off questions requiring them to choose among different information packages. The surveyors first described key attributes of the traffic information services and ways in which they could vary, then asked the respondents to think about the potential benefits they might receive from them in the context of their own individual travel. Finally, the respondents were asked to indicate preferences between pairs of hypothetical information services described in terms of their attributes. Surveys were administered via a computer. The respondents were generally satisfied with their prior experiences with in-vehicle navigation systems, and readily understood the potential system attributes and features that were described to them.

Information attributes, and their possible values, that were studied in the survey included:

- update frequency: twice a day, several times an hour, every five seconds;
- prescriptive or descriptive messages: minimum time route recommendation or information on current delays;
- geographic coverage: main expressways only, expressways and arterials, door-to-door; and
- price: free, $5/month, $10/month (Seattle), $15 or $25/month (Chicago and Boston)

Additional questions investigated respondents into the absolute importance of some attributes: whether they were considered essential, reasonable or perhaps more in the nature of a bonus.

Based on the definitions of two alternative information service packages and respondents' stated preference for one or the other, simple logit models were estimated.

The study obtained results in a number of areas.

Geographic coverage and update frequency were both important attributes; logit model coefficients for the minimal level of provision of both of these had approximately similar coefficients. In general, utilities associated with the basic level of provision were generally higher than the incremental utilities from more enhanced levels. With respect to geographic coverage, door-to-door coverage was perceived as having little or no incremental benefit compared to coverage of freeways and arterials. Similarly, information updates several times an hour were clearly preferred to static information, but the added value of nearly continuous updates was small to negligible.

Few respondents were indifferent to the type of guidance -- prescriptive or descriptive -- provided by the system; they strongly preferred either one or the other. A majority of all respondents preferred to receive description information (delays), although about 20% preferred prescriptive route guidance. Where sample sizes were large enough to allow such investigation of gender-related effects, it was found that women were more likely than men to prefer prescriptive guidance.

Analysis of the responses to pricing questions yielded willingness to pay results that may not be fully reliable. Most respondents indicated a willingness to pay some amount as their most preferred option. The estimated willingness to pay ranged from \$8-\$10/month in Seattle, from \$28-\$36/month in Chicago and from \$8-\$20/month in Boston, depending on the particular service attributes. These are generally higher than would be expected from other, more informal, analyses of user willingness to pay. The authors propose a number of possible explanations for these anomalous results, without reaching a definite conclusion.

A number of survey design and analysis issues are touched on in the papers. Among these are the possible presence of response bias (respondents give positive answers thinking it will please the surveyor) and non-commitment bias (respondents overstate their willingness to pay because no money is actually involved in answering); suitable survey design can often minimize these effects, although the high willingness to pay estimates could well result from non-commitment bias. The econometric problem of correlated error terms in the response by a single person to multiple related questions was addressed by estimating random parameter logit models, but it was found that this computationally-intensive technique did not result in estimates significantly different from those obtained using simple logit models, so the latter were applied thereafter.

Mehndiratta, S. R., Kemp, M., Peirce, S., and Lappin, J. (2000). "Users of a Regional Telephone-Based Traveler Information System - A Study of TravInfo users in the San Francisco Bay Area." *Transportation*, 27, 391-417.

This is a report on a 1998 survey of a small (312 respondents) sample of users of the TrafInfo Travel Advisory Telephone Service (TATS) in the San Francisco Bay Area. The survey was intended to obtain information about the characteristics of TATS users; to identify distinct market segments within the overall set of users; and to explore the preferences of the different market segments for alternative possible TravInfo data features, such as more frequent updates, increased geographic coverage, and higher level of customization.

In addition to providing basic information about their socio-economic characteristics and their travel habits and experiences, respondents were asked to indicate their level of agreement or disagreement with a set of attitudinal statements ranging from personality type indicators to attitudes towards traffic information. Responses indicated that the group, as a whole, fits a technology enthusiast and lead adopted profile, combined with a strong interest in traffic and reliable information about travel times.

These responses were further analyzed using factor analysis and cluster analysis techniques common in marketing studies. Four factors accounted for roughly 60% of the total variance in the data. The score of each respondent with respect to each of the factors was computed, and cluster analysis was used to identify groupings of respondents having similar values for the four scores. 91% of the respondents fell into one of four distinct clusters. The characteristics of members in each cluster were then examined in order to obtain its characterization. The four market segments identified in this way are:

- regular stable users (51% of the sample), characterized by being better educated, technologically sophisticated but not concerned by trends, and dissatisfied with the quality of broadcast traffic reports;

- occasional users (16% of the sample), more likely to be women, slightly less educated than the rest of the sample, uncomfortable with technology and maps, and more likely than the rest of the sample to accept route guidance and to make route adjustments in response to traffic reports;

- heavy users (14% of the sample), characterized by a desire to plan ahead, comfortable with technology and maps, satisfied with the quality of broadcast radio reports, and strongly prefer to receive information on delays rather than route recommendations; and

- technologically trendy, regular users (10% of the sample), mostly male, into cars and technology trends, like to predict trip times reliably but don't worry about being late, and have a preference for delay information over route recommendations.

Respondents were also asked direct questions about preferences for possible information quality improvements, as well as tradeoff questions intended to elicit information about their valuation of such improvements.

The most preferred improvements involved higher information update frequency (41% wanted continuous updates, 14% wanted updates at least every five minutes) and extended geographic coverage (22% wanted coverage of freeways and arterials, 9% wanted coverage of all roads including local streets). Personalization and customization of the provided information (for example, by receiving personalized route condition reports or automatic personal alerts about unusual conditions) were least preferred. 57% of the respondents said that they were unlikely to pay to receive traffic information.

However, responses to the tradeoff questions were used to estimate discrete choice models for the entire sample and for some of the identified market segments; from these models, indications of respondents' willingness to pay for the various enhancements could be determined. Tradeoff question results generally confirmed the absolute preference results. For the full sample, the willingness of pay for information updates at least every five minutes was $5.12, while that for continuous updates was $5.81. Willingness to pay for complete network coverage was $2.57. (These values should be interpreted as relative rather than absolute amounts.) Models estimated only for those respondents who indicated that they were prepared to pay in order to receive higher quality information showed higher values of willingness to pay, as would be expected.

Mehndiratta, S. R., Kemp, M., Lappin, J., and Nierenberg, E. (2000) "Who are the likely users of ATIS? Evidence from the Seattle region." *Transportation Research Board 79th Annual Meeting*.

This paper reports findings of an analysis of a 1997 ITS supplement to the Puget Sound Regional Council's (PSRC) transportation panel travel diary study. The analysis concerns the use of currently-available travel information and claimed interest in ATIS services by panel members. The survey data is especially interesting because of its size and good representation of the overall general population, and because Seattle has invested relatively heavily in various ITS technologies.

The 1997 wave 7 survey covered roughly 2000 households and included an ITS supplement in which regular commuters were asked roughly three dozen attitudinal statements relating to general opinions about innovation, change, thrift, forethought and technology; general experience of and attitudes towards travel delays; and experience of and attitudes towards travel information. Respondents were asked to indicate, on an eleven-point scale, how much they agreed or disagreed with each statement.

A first analysis of the data led to the identification of "likely ATIS users" based on their current use of and reactions to traffic information, as represented by their responses to survey questions about prior trip changes made in response to pre-trip and en route traffic information and propensity to access various sources of traffic information.

An initial analysis of the socio-economic characteristics of likely ATIS users attempted to define them in terms of market segments defined a priori on the basis of stereotypes such as road warriors, commuting mothers, high income commuters and middle-aged men. This segmentation was only partially successful. Despite the fact that people belonging to these stereotypes pursue lifestyles that suggest that they would perceive high utility and benefits from ATIS services, the incidence among them of "likely ATIS users" was no greater than in the general population (around 7.5%).

Accordingly, the full set of PSRC data was processed using more analytical methods from market research. Factor analysis was used to reduce the large number of demographic and attitudinal variables into a much smaller set of uncorrelated factors, consisting of linear combinations of the basic variables. Four factors were extracted, accounting for roughly 60% of the variance in the data set. Next cluster analysis was applied to identify groups of respondents related by virtue of their similar factor scores. Eight distinct market segments were identified in this way, representing roughly 90% of all respondents. The incidence of likely ATIS users in each category was then analyzed, providing an understanding of the relationships between likely

ATIS use and other characteristics of each segment. The following list describes the identified segments and the percentage of each that are likely ATIS users:

- control seekers: people who plan ahead, are not averse to innovation, at ease with technology and make frequent trips: 11.3% of these are likely ATIS users;

- web heads: people who are interested in technology and traffic information and are concerned that the information they receive is up to date: 10.4% are likely ATIS users;

- rigid routines: people who follow the same routine but may make small adjustments based on traffic information: 8.6% are likely ATIS users;

- buyers of value-added services: people who value assistance in daily activities, including tripmaking: 8.0% are likely ATIS users;

- wired with children: people with high incomes and long commutes; they value convenience; 7.9% are likely ATIS users;

- trendy and casual: people who use pagers and cell phones to stay in contact, but are not particularly interested in traffic information: 5.4% are likely ATIS users;

- male technophobes: older males who are uncomfortable with technology and less likely to change travel behavior: 5.3% are likely ATIS users; and

- mellow techies: people comfortable with computers and the Internet but little interest in traffic conditions and little concern about being late: 3.9% are likely ATIS users.

It can be seen that the first several groups have significant concentrations of likely ATIS users.

Mehndiratta, S. R., Peirce, S., Kemp, M., Lappin, J., and Cluett, C. (2000). "A Profile of the Emerging ATIS Consumer: Evidence from Five Metropolitan Model Deployment Initiative Sites." *ITS Quarterly*, 8(1).

This paper reports findings of an analysis of ATIS customer characteristics, and in particular proposes a segmentation of the market for ATIS services. The analysis draws on data from two sources:

- the continuing Puget Sound Regional Council (PSRC) survey, consisting of a panel of representative households accustomed to providing detailed travel diary information for all household members every one or two years. The 1997 panel wave included a supplementary questionnaire concerning the use of travel information sources in commute trips. See (Mehndiratta, Kemp et al. 1999b); and

- five Metropolitan Model Deployment Initiative (MMDI) projects, for which six core attitudinal questions relating to travel information use were included in more general surveys of the test populations. Four of the projects were in Seattle, Washington and the fifth was in Tempe, Arizona.

As noted in (Mehndiratta, Kemp et al. 1999b), analysis of the PSRC data identified eight distinct potential market segments, of which two are likely to contribute the most ATIS customers. These were dubbed the control seekers and the web heads:

- control seekers (19% of the PSRC sample) are characterized by a desire for control and knowledge, want to plan ahead and stay accessible, and tend to be budget conscious; and

- web heads (16% of the sample) are marked by very high usage of computers and the Internet both at home and at work.

It was expected that additional potential ATIS users would fall into three other identified segments: low-tech pre-trip information seekers (22% of the sample), who like to plan a trip before departure; buyers of value-added services (10% of the sample), who may value travel information such as route guidance; and wired with children (7%) who may value the utility that ATIS services can provide.

Further analysis of the PSRC data used discriminant analysis to identify a minimal set of variables that could be used to assign respondents to one of the eight clusters with acceptable accuracy. The discriminant function was then used to classify the respondents from the MMDI survey populations.

Application of the discriminant analysis results to the MMDI survey populations in order to classify respondents into these segments gave results that were mostly consistent with expectations. The vast majority of web-based ATIS users are web heads or control seekers. However, web heads are not significant users of non-web-based ATIS services. On the other hand, low tech pre-information seekers have a significant demand for non-web-based services. Finally, an additional market segment from the PSRC analysis was consistently identified as an ATIS user across most of the MMDI projects. These were the mellow techies, people comfortable with computers and the Internet but with a low level of control-seeking behavior. Surprisingly, in the PSRC survey, few members of this segment indicated that they accessed or used existing traffic information sources.

An overall conclusions of the study are that potential ATIS market segments can be successfully identified through analysis of attitudinal surveys. Technology was seen to play a complex role in mediating access to ATIS services: on the one hand, it may be a barrier to entry for segments less comfortable with it; on the other, some segments seem to demand ATIS primarily as an exercise in technology. Finally, market segment analysis only serves to identify potential users of ATIS services; for these users to actually demand and use ATIS services, other conditions relating to trip and network characteristics, as well as to the quality of the ATIS services, must be met.

Mishalani, R. G., McCord, M. R., and Lee, S. "The Value of Real-Time Bus Arrival Information Under Various Supply and Demand Characteristics." *ITS America 10th Annual Meeting*, Boston, Massachusetts.

This paper investigates the value of bus arrival time information systems based on the reliability of the information to passengers waiting to board an upcoming bus. The methodology adopted in the paper explicitly models the effect of both supply and demand characteristics on this reliability, and therefore system value. The evaluation methodology relies upon modeling the following four main elements: 1) bus arrival information system (BAIS), 2) bus operating characteristics, 3) operator or broadcaster who provides bus arrival time information at stops, and 4) prospective passengers arriving at bus stops and receiving the information provided by the broadcaster.

To assess the value of bus arrival information systems, the methodology employs a comparative approach. Three alternative BAIS specifications are defined to reflect a spectrum of real-time vehicle location data available to the broadcaster. The three specifications consider no real-time data (BAIS1), limited data (BAIS2), and comprehensive data (BAIS3). BAIS1 is adopted as a base case. The values of the other two alternatives are quantified in relation to this base case. For all three alternatives, a broadcaster is assumed to provide predicted bus arrival times at a stop based on knowledge relating to the operations of the system as reflected by historical characteristics and the real-time vehicle location data available. Furthermore, it is assumed that the broadcaster is capable of continuously providing the bus arrival time information. In addition, it is assumed that all passengers arriving at the stop board the upcoming bus and that the utility each passenger derives from this information depends on the difference between the time the next bus is predicted to arrive and the actual time at which the next bus arrives.

In predicting the time until the next bus arrival to broadcast at any instant, the broadcaster maximizes the utility of the passenger assumed to arrive at that instant. In doing so, the broadcaster depends on his/her knowledge of the waiting time distribution for that passenger. If real-time data is not available, this waiting time distribution is simply derived from the historical bus headway distribution. When real-time data is available, the broadcaster can update the unconditional waiting time distribution by conditioning it on the real-time data. This updating allows for the selection of a broadcast time that on average results in a higher passenger utility. The performance of each alternative BAIS is then characterized by the expected value of the realized passenger utilities evaluated across the passenger population. This is equivalent to the expected utility of a randomly selected passenger (also referred to as a representative passenger).

The utility of bus arrival information to a specific passenger is assumed to be a function solely of the difference between the broadcast time received by the passenger at the instant of his/her arrival to the stop and the actual time that the passenger waits for the bus. Furthermore, the utility is assumed to decrease linearly as the discrepancy between the predicted and the actual waiting times increases. To arrive at this expected utility for each of the three BAIS alternatives given passenger behavior (i.e. demand) and bus operations (i.e. supply) characteristics, the following three steps are followed:

- Determine the conditional passenger waiting time distribution given real-time data under the three BAIS alternatives.

- Model the broadcaster's determination of the optimal broadcast time as it varies over time, and

- Based on the optimal broadcast time and passenger utility, determine for each of the three BAIS alternatives the expected utility of a random passenger reflecting the performance measure of interest.

Under BAIS1, the expected utility of a specific passenger is the same for all passengers since the broadcaster's view of the waiting time distribution does not vary across passengers due to the lack of availability of real-time vehicle location data. Therefore, the expected utility of a random passenger is equivalent to the expected utility of any and each passenger. Under BAIS2 and BAIS3, the expected utility for each passenger differs according to the real-time data available to the broadcaster at the time of passenger arrival. Therefore, the expected utility of a random passenger in these cases is determined by integrating the expected utility of an individual passenger as viewed by the broadcaster over the distribution of the variables representing the real-time data.

Under some set of assumptions (such as an exponential bus headway distribution, a piecewise linear utility function, and Poisson passenger arrivals), these expected utilities can be derived analytically. However, when solving for the expected utility using a variety of bus headway distributions, utility functions, and passenger arrival processes, closed form analytical solutions can become intractable. Therefore, Monte Carlo simulation is used to compute the expected utilities under various supply and demand scenarios. Bus headways are generated randomly from a normal probability density function truncated to avoid negative outcomes. In considering various operations related scenarios, passenger arrivals are generated assuming exponential inter-arrival times. The Poisson arrival assumption is also relaxed subsequently to explore the effect of arrival processes that reflect passengers attempting to follow a schedule.

The results indicate that the type of real-time data available to the broadcaster under the three BAIS alternatives and the characteristics of the operations of the bus transit system have clear effects on the expected utility. Specifically, BAIS3 is better than BAIS2, which is better than BAIS1. Moreover, the standard deviation of the headway distribution along with the nature of the headway spatial correlation have a clear influence on the expected utility under BAIS3. On the other hand, the effect of the passenger arrival process under BAIS3 is found to insignificant based on the examined Poisson and saw-tooth behavior.

Mollenhauer, M. A., Hulse, M. C., Dingus, T. A., Jahns, S. K., and Carney, C. (1997). "Design Decision Aids and Human Factors Guidelines for ATIS Displays." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 23-61.

Landau, F. H., Hanley, M. N., and Hein, C. M. (1997). "Application of Existing Human Factors Guidelines to ATIS." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 397-443.

Wochinger, K., and Boehm-Davis, D. (1997). "Navigational Preference and Driver Acceptance of Advanced Traveler Information Systems." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 345-362.

Kantowitz, B. H., Becker, C. A., and Barlow, S. T. (1993). "Assessing Driver Acceptance of IVHS Components." Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting, 1062-1066.

Advanced Traveler Information Systems (ATIS) incorporate functions that enable drivers to access information that was previously unavailable or was retrieved from domains outside of vehicle. This research explores the decisions designers must take when developing ATIS displays. It also describes a design support process that has been developed to help formulate answers that reflect current human factors research and accepted design principles. Examples of decision tools that make up this process will be provided along with a description of how these tools can be used together to aid in the design process. In addition, specific results are also presented and discussed.

When giving drivers access to ATIS systems inside the vehicle, designers must consider not only usability, but also safety. One of the primary concerns is that ATIS will inadvertently reduce safety instead of improving it. The overall impact of ATIS on driving will depend largely on driver's ability and desire to successfully use the information provided. If ATIS is not developed to be driver friendly and easily utilized by the majority of drivers, its overall effectiveness will suffer. Designers must answer the following when developing displays for ATIS, which will affect or have an impact on both the safety and usability of the system: (i) What information should be included in the ATIS that is being developed? (ii) What functions of the ATIS should the driver be allowed to use? (iii) To which sensory modality (e.g., auditory, visual, tactile) should information items be allocated? (iv) What format (e.g., text, map, tone, voice) should be used to present the information? The ultimate goal of this research is to develop usable design tools that generate guidelines for ATIS designers. All the criteria developed for the tools in this analysis relate only to one aspect of the design – namely, the human factors issues of safety, usability and preference/acceptance.

To analyze the information format options, “trade study” analysis is used to aid in design decisions. These analyses serve as systematic aids for complex decision making. Due to constraints imposed by cost, techniques and so on, designers cannot create designs that are optimal in every way. To meet one objective, they often must compromise another. Thus, throughout product development, designers must determine the combination of criteria that best satisfies the decision objectives. The trade study analysis enforces two primary objectives of good design practice. First, the designers consider more design options. And second, the designers avoid bias generated from preconceptions about the design.

The design tools used for this analysis are: (i) Information items for a given conceptual system; (ii) Functional information grouping; (iii) Sensory modality allocation; (iv) Information-type categorization; (v) Information criticality assessment while driving analysis; (vi) Trip status allocation; (vii) Display format allocation analysis; (iix) Development of conceptual designs; (ix) Total display-information processing overloads assessment.

The paper than discusses the results of performing the previously defined trade study process on a list of over 400 general ATIS information items. Specific results and design implications are provided, along with comments about the applicability and usability of the tools themselves.

The paper by Landau, Hanley and Hein is very similar to the one described above in that it describes ATIS functionality, driver-vehicle interface components, and existing guidelines with discussion and recommendation concerning their limitations and research needs. As an initial step in the new system design activity, human factors practitioners consult existing guidelines as an aid in defining the functionality and form of the new system.

Design guidelines are a critical source of information for human factors and system designers to access when developing and specifying the architecture, functionality and physical interface of the system. Human factors practitioners and system designers must determine which guidelines are relevant, and then proceed to develop design rules appropriate for the specific system under development. Because the process of formulating a guideline recommendation depends on characterizing the driving environment and its tasks, several criteria are used as standards against which the guideline data are compared.

The following topic areas are reviewed for guideline availability and applicability to an ATIS:

- input methodology: The design of the input mechanisms for an in-vehicle system must consider the accuracy and speed required for transactions;

- display and information characteristics: The research covers guidelines related to both legibility and readability of a display. Legibility is the rapid identification of single characters that may be represented in non-contextual format. Readability is the ability to recognize the form of a word or group of words for contextual purposes;

- auditory display characteristics: Auditory displays include both nonverbal and verbal aural displays. Nonverbal displays use auditory alerting signals to signify events. Verbal displays use voice signals or messages to signify events and to provide more complex information. Auditory displays can supplement visual systems;

- human-computer interaction: The interaction between a driver and an ATIS system will be modeled to a great degree on human-computer systems because the nature and complexity of the transactions are so similar to current computer interfaces. Therefore, the applicability of human-computer interface guidelines is reviewed; and

- navigation information format: Navigation information is typically portrayed by maps that provide direction and distance relationships in a plan view presentation. Another type of navigational format is turn-by-turn sequential list.

The guidelines that are reviewed uniformly lack the supporting data necessary to specify driver-vehicle interface guidelines.

The paper by Wochinger and Boehm-David is another similar research (to the previous two) on user acceptance of ATIS products and services. The successful implementation of ATIS depends on user acceptance of its products and services. Information on user acceptance could be applied to the design of ITS products and services, as well as to the development of ATIS implementation strategy.

User acceptance is particularly important to the successful implementation of ATIS because the accuracy of traffic information it conveys is dependent on the number of ATIS equipped vehicles. Receiving inaccurate information from an ATIS device may break the trust the driver has in the system and lead to user rejection. Consumer rejection of ATIS, in turn, may lead to decreased system reliability and accuracy. ATIS is unique in that the degree of consumer use affects system effectiveness. Thus, to optimize ATIS accuracy, initial acceptance of ATIS should be maximized.

The results of the study indicate that the drivers showed strong differences in their initial preferences for maps and text directions. However, most of the participants rated ATIS higher than the other aids after a “hands on” experience with it. Older drivers in particular may be unlikely to embrace a technologically innovative system. An ATIS implementation strategy can facilitate user acceptance by presenting information to positively influence customer reaction to ATIS. For example, descriptions of ATIS that are targeted at older drivers could emphasize the capacity of ATIS to enhance the safety and mobility of travelers. Likewise, educating users about potential system weaknesses might lead to realistic expectations of ATIS technology and the maintenance of trust in the system even in the face of less than perfect performance.

The paper by Kantowitz, Becker and Barlow deals with user acceptance of ATIS in a way very similar to that adopted in the aforementioned two papers. In addition to ATIS this study also addresses the user acceptance criteria of Commercial Vehicle Operation (CVO).

Nakayama, S., Kitamura, R., and Fujii, S. "Drivers' Route Choice Rules and Network Behavior: Do drivers become rational and homogeneous through learning?" *Transportation Research Board 80th Annual Meeting*.

The purpose of this study is to examine whether drivers become rational and homogeneous as they learn over time. A model system that simulates driver learning is applied to investigate how drivers' route choices evolve over time. Based on the model results, the validity of the hypotheses underlying network equilibrium is also investigated. This study assumes that a driver chooses a route based on a limited number of simple rules and examines which rules tend to be adopted by the driver. The simulation model represents the situation where drivers make repeated route choices on the same road network. The model consists of two sub-models, a route choice model and a travel time model. In the route choice model, the route a driver chooses is decided by the set of rules he holds, which are updated based on his experience. The travel time model calculates the route travel times based on the flows resulting from drivers' choices.

Different drivers choose routes differently; travel experience would certainly affect choice procedures. The patterns of thinking underlying a driver's route choice are called route choice rules in this study. The study considers four route choice rules:

- no switching, in which the driver continues to travel on one route
- random switching, where the driver switches routes purely randomly;
- experience based, where the driver evaluates alternative routes based on the experiences he recalls, then chooses that route that is evaluated to be the best; and
- rational, where the driver evaluates alternative routes rationally based on all experiences, then chooses the best route.

The driver is assumed to attempt to minimize his travel time through route choice, although he is not assumed to always succeed in doing so. He has a set of alternative rules for route choice, and the four types of route choice rules could all become alternative rules for him. He chooses a route by applying one of these rules. Each route choice rule has a rating and the rating is updated over time. The driver is assumed to use that rule whose rating is the smallest. Each rule suggests a route, and the driver takes the route indicated by the rule he chose. Route choice is made in two stages: in the first stage, the driver chooses a rule; in the second stage, the chosen rule instructs the driver which route to take.

If the assumption that the driver is rational and homogeneous holds true, then all drivers should take the rational rule even if they started with a limited set of rules. On the other hand, if not all drivers adopt the rational rule starting with a limited set, then not all of them will do so either when they start with a more comprehensive set of rules.

Learning in this study refers to the process of updating alternative rules based on experience, and deciding which rule to apply in choosing a route. This process is formulated using the concept of genetic algorithms, where genetic strings that have higher values of fitness survive. In the genetic algorithms of this study, that alternative rule which has the largest rule performance indicator value is replaced by a new alternative rule. The type of the new alternative rule is determined randomly. A driver is assumed to know the travel time on the route he has taken for his trip, but not travel times on the other routes. Because the information he can acquire is thus limited, he cannot objectively judge which rules he should be using for his route choice. It can then be expected that he cannot help but judge that a rule is superior if, according to his experience so far, he has traveled faster with this rule than with any other rules. A performance indicator is thus introduced to assess how well each rule has been performing.

Route choices made by the respective drivers in the model system are aggregated and traffic volume is determined for each route. Travel time is then calculated for each route using the Bureau of Public Roads (BPR) function. The traffic flow model is simplified based on several assumptions. Most important is that the starting times of the trips made by the drivers in the system are uniformly distributed over time. Simulation experiments were performed using 4000 simulated drivers who make one trip each day on a two-route network.

The results of the study can be summarized as follows. First, it is shown that the system does not necessarily converge to Wardrop's user equilibrium. Second, drivers do not become homogeneous and rational as network equilibrium presupposes; instead, some drivers remain less rational and heterogeneous drivers comprise the system. Third, drivers' attitude towards uncertainty becomes bipolar. Fourth, some drivers are occasionally deluded.

The results of the simulation analysis imply the need for a critical examination of the validity of network equilibrium as a framework for network flow analysis. Although equilibrium analyses have made substantial contributions to our understanding of network behavior, this study has pointed out fundamental problems with its assumptions. It has shown that new insights can be gained of network behavior by examining the drivers' behaviors and cognitive processes underlying their route choices.

Ng, L., Barfield, W., and Spyridakis, J. (1997). "Survey Methodologies for Defining User Information Requirements." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 325-357.

This chapter is a review of several methodologies for conducting surveys to define user information requirements for Intelligent Transportation Systems (ITS), including ATMS, ATIS and CVO applications.

It first provides a relatively brief review of standard methods of survey design methods. Next, it presents in some detail several case studies of relevant travel surveys conducted at the University of Washington, including an initial survey to define commuter information requirements, a follow-up survey for the same purpose, and a survey to define user requirements for ATIS and CVO deployments. Finally, there is a brief qualitative discussion of various data analysis methods including basic descriptive statistics, ANOVA, cluster analysis and modeling.

The chapter is a high-level summary of survey methodologies. The detail it provides in describing the case study surveys is interesting, however its discussion of survey design and analysis methods is too qualitative to serve as a reference for practitioners.

Ng, L., and Barfield, W. (1997). "Determining User Requirements for Intelligent Transportation Systems Design." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 325-357.

Based on results obtained from surveys of potential users of ITS applications including ATMS, ATIS and CVO, this chapter presents some of the basic information requirements that are beginning to emerge from the literature.

It begins with a brief review of the literature on research (through the early 1990s) into user requirements, addressing the questions: what information do users want; in what format should the information be presented; where and when do travelers need information; are there different user groups in terms of their travel information needs; how do socioeconomic characteristics influence information needs; and how does stress influence driving behavior. The review of each question generally mentions a few articles on the subject but does not attempt to be comprehensive. Reference to prior work is generally to that carried out at the University of Washington by Barfield, Conquest, Haselkorn, Spyridakis and Wenger, among others.

The next section is a discussion of user requirements for ATIS and CVO applications, based on surveys conducted by the authors and used as case studies in (Ng, Barfield et al. 1997). The surveys covered private drivers, commercial drivers and dispatchers of commercial vehicles. Alternate route information was highly valued by all these users. Of interest, the respondents indicated that the main reasons for choosing an alternate route were accidents, traffic volume levels and road construction activities. Around half the private and commercial drivers cited the gain in time by rerouting as the reason for switching routes. Accuracy and currency were found to be the most important attributes of the information provided by an ATIS or CVO application.

The authors consider next the different information requirements of private drivers, commercial drivers and dispatchers, including possible subgroups within each of these categories. With respect to private drivers, the authors reference their earlier research, which identified commuter subgroups in terms of their propensity to change route and departure time. They also present a second case study of defining private driver and commercial driver subgroups, on the basis of their rankings of the importance of various travel characteristics such as trip time, distance, safety and enjoyment. They applied cluster analysis for this purpose.

A further discussion considers user information requirements based on trip and socio-economic characteristics, considering separately driver behavior pre-trip, en route and post-trip. Interesting conclusions relate to the importance of drivers' observations of traffic conditions in motivating a route switch, and suggest live displays of real-time traffic conditions as a component of a traffic information system. Another interesting conclusion relates to the importance of en route and post-trip confirmation of the validity of switching decisions actually made by a driver.

Ng, L., and Mannering, F. L. "Statistical Analysis of the Impact of Traveler Advisory Systems on Driving Behavior." *Transportation Research Board 79th Annual Meeting*.

This paper explores the effects of driving behavior using in-vehicle and out-of-vehicle traffic advisory information. A travel choice simulator installed in a car frame and interfaced with the car controls and a windshield display was used to collect data on driver speed behavior under four different advisory-information conditions: (i) driving with in-vehicle information, (ii) driving with variable message information (out-of-vehicle information), (iii) driving with both types of messages present, and (iv) driving with no information present.

Of interest in this study was the speed response of drivers to messages about adverse weather and driving conditions. The simulator realistically depicted a mountain road in Washington State subject to fog, snow and ice in the winter. Three types of messages were displayed: fog ahead, curvy road ahead, snowplows ahead. The analysis used three-stage least squares to estimate a simultaneous equations model of travel speed mean and standard deviation, including as independent variables the characteristics of the road, the environment, the driver and the type of information provided.

The findings of this study showed that for long distances, no significant differences in speed and standard deviation of speed existed regardless of the traveler-information system used. However, for shorter distances, significant changes in speeds were identified. These findings suggest that, after a period of slowing in response to advisory information, drivers then compensate by driving faster.

No significant difference in mean speeds were observed whether a given message (or sequence of messages) was presented (at the same road locations) on a VMS or on an in-vehicle unit. Some messages (curvy road ahead) actually caused drivers to increase their speed.

Oh, J.-S., and Jayakrishnan, R. "Temporal Control of Variable Message Signs towards Achieving Dynamic System Optimum." *Transportation Research Board 80th Annual Meeting*.

This paper explores how close the dynamic flow splits resulting from the temporal control of variable message signs (VMS) can come to a dynamic system optimum (DSO). While VMS is generally considered not useful in providing flow splits across alternate paths at any given time, temporally changing VMS messages may achieve certain desirable flow splits over time, though this depends substantially on the driver compliance behavior. To meet this objective, first, a dynamic system optimal traffic assignment problem needs to be solved to compare any results form temporal VMS guidance to a benchmark. Dynamic optimal route guidance solution can be obtained by solving dynamic traffic assignment (DTA) problem. A dynamic optimal solution for VMS route guidance can also be found by solving the DTA problem from a VMS location. The problem can be formulated as a mathematical problem and heuristically solved. The decision variables in the problem are path flows from the VMS location to target destination. This paper introduces a practically applicable method providing a set of such time-dependent optimal paths for a given time horizon. At every time step, an optimal path is selected from a set of mutually exclusive alternatives that can be expresses by VMS. This predictive approach becomes more realistic when drivers' compliance behavior model is incorporated. This paper tests the proposed algorithm and compares with the other route guidance methods via off-line simulation experiments. The main objective is to investigate path flow pattern of temporal VMS guidance and to explore how much the pattern differs from that of dynamic system optimum.

In this study, to determine time-dependent, system optimal path flows, a macroscopic traffic simulation program, DYNASMART is used. The path flow based DSO for VMS route guidance provides time-dependent optimal splits between alternative routes associated with a VMS. The time-dependent optimal splits may be used as target value; however, achieving such splits is difficult. It is not possible for VMS to provide multiple path guidance at a time since VMS display hardware can often show only one path at a time. That is, the time-dependent optimal path splits cannot be directly translated into a VMS message. A possible way of using such splits may be to recommend a path with highest split.

In the case of a DSO problem for temporal VMS route guidance, the route recommendation is same during a time period, but can change only over time. That is, the temporal route guidance selects the optimal path for a time period. The problem is formulated as a mixed integer programming problem where decision variables are a set of time-dependent optimal paths. Difficulty of the problem arises from the all-or-nothing nature in assigning the path flows from VMS to corresponding destination. In contrast to the path flow based DSO, the iterative approach with MSA update cannot be applied for the problem. This paper develops a heuristic algorithm that spreads flow over time rather than spreading flow over alternatives within discrete time interval. The heuristic method seeks the best path that can be expressed by a VMS message for each time step.

A model framework was also developed to capture drivers' compliance behavior. The model includes a number of variables affecting drivers' decision associated with VMS. It is a binary logit model structure and takes three different types of variables into consideration – drivers' characteristic variables, traffic characteristic variables, VMS characteristic variables.

Simulation experiments were performed to evaluate performance of the proposed method and to explore how much the resulting path flow pattern differs from the dynamic system optimal pattern. The proposed method was compared with three other methods, such as the path flow based DSO, temporal average cost routing, and instantaneous feedback routing. First, simulation experiments were conducted under 100% compliance assumption to compare algorithmic performance. Then, for more realistic simulation, experiments were repeated with drivers' compliance model.

The results indicated the temporal VMS guidance's capability to be a comparable method towards achieving the dynamic system optimum. In the comparison, the marginal cost route guidance (SO) performed better than the average cost routing (SO). The difference decreases as the VMS update interval increases because the marginal effect disappears when a long update interval is used. While the temporal VMS recommends a path at a time, the path flow based approach provides an optimal split for each time step. Even though the temporal VMS guidance methods do not split flows during a time step, path flows are dispersed between alternatives over time and the cumulative flow is ended up with a similar split as the path flow based approach. Interestingly, both approaches show similar cumulative path flow splits regardless of update interval. The results have shown that the path flow pattern and network performance comparable to the dynamic system optimum can be achievable via temporal VMS guidance.

Owens, D. (1980). "Traffic Information Broadcasting: Driver Reaction to Two Kinds of Traffic Message -- A Pilot Study." *TRRL Supplementary Report 603*, Transport and Road Research Laboratory.

From the abstract:

"Results are presented of a study which examined drivers' ability to interpret and use information broadcasts about road traffic incidents to find alternative routes. The experiment was designed to simulate some of the characteristics of an operational dedicated traffic broadcasting system by presenting drivers with messages concerning a major, though hypothetical, incident along the route they were traveling. Two kinds of traffic message were compared: one containing details of a recommended alternative route, the other merely informing drivers of the presence of a road blockage. All messages gave details of the nature, location, duration and expected delays resulting

"The main criterion adopted for assessing message effectiveness was the proportion of drivers who successfully avoided the blockages described in the broadcasts; a secondary analysis evaluated and compared the generalized costs of successful diversions. Overall, three-quarters of the journeys resulted in successful diversions. Drivers given positive diversion advice were generally more successful than other drivers although their diversion route costs were about the same. As expected, knowledge of the local road networks contributed to successful navigation round the blockages."

Ozbay, K., Datta, A., and Kachroo, P. "Modeling Route Choice Behavior Using Stochastic Learning Automata." *Transportation Research Board 80th Annual Meeting*.

This paper proposes the use of stochastic learning automata (SLA) to model drivers' route choice behavior in a way that captures day-to-day learning. The concept of learning automaton grew from a fusion of the work of psychologists in modeling observed behavior, the efforts of statisticians to model the choice of experiments based on past observations, and the efforts of system engineers to make random control and optimizations decisions in random environments. In the case of route choice behavior modeling, which also occurs in a stochastic environment, stochastic learning automata mimic the day-to-day learning of drivers by updating the route choice probabilities based on information received and driver experience. The stochastic learning automata approach adopted in this paper is an inductive inference mechanism which updates the probabilities of its actions occurring in a stochastic environment in order to improve a certain performance index, i.e. travel time of users.

Generally, travelers cannot foresee the actual travel cost that they will experience during their trip. However, they can anticipate the travel cost based on costs experienced during previous trips with similar characteristics. It is possible to view the problem of route choice as a problem in learning.

A stochastic automaton attempts a solution of a problem without any a priori information on the optimal action. One action is selected at random, the response from the environment is observed, action probabilities are updated based on that response, and the procedure is repeated. A stochastic automaton acting as described to improve its performance is called a learning automaton.

Advantages of using stochastic learning automata for modeling user choice behavior are:

- unlike existing route choice models that represent the learning process as a deterministic combination of previous days' and the current days' experience, SLAs represent the learning process stochastically; and

- SLAs can easily capture non-linear combinations of explanatory variables in the general utility function used in route choice models. This may present an important improvement over existing route choice models since route choice may not depend on a linear combination of explanatory variables.

A linear reward penalty scheme was proposed to represent the day-to-day learning process. In order to calibrate the SLA model, an internet based Route Choice Simulator (IRCS) was developed. The IRCS is a traffic simulation model that represents within day and day-to-day fluctuations in traffic and was developed using Java programming. Data collected from the experiments were analyzed to show that the participants' learning process can be modeled as a stochastic process that conforms to the penalty scheme within the stochastic automata theory. The model was calibrated using experimental data obtained from a set of subjects who participated in the experiments conducted at Rutgers University. The calibrated SLA model is then applied to a simple transportation network to test if global user equilibrium, instantaneous equilibrium and driver learning have occurred over a period of time. It is observed that the developed stochastic learning model accurately depicts the day-to-day learning behavior of travelers. Finally, it is shown that the sample network converges to equilibrium, both in terms of global user and instantaneous equilibrium.

Peeta, S., Ramos, J. L., and Pasupathy, R. "Content of Variable Message Signs and On-line Driver Behavior." *Transportation Research Board 79th Annual Meeting*.

This paper focuses on the relationship between the content of VMS message and driver route diversion rates. If different message contents used to describe the same situation prompt different diversion rates, then the message content may be used as control variable by the traffic controller to generate favorable network conditions in the real-time operation of the system while conserving the integrity of the information. This may have key implications for the design and operation of VMS-based traffic information systems, primarily in terms of credibility and effectiveness of information for motorists. Controlling the level of detail of displayed VMS information without impinging on its veracity can potentially aid user confidence in VMS-based information provision. Also, solution methodologies for networks installed with VMS may focus on message content as a primary mechanism to improve network performance. The main objective of this study is to build driver behavior models that predict the diversion probability of an individual under a specific type of VMS message. In building these models, the study examines the relative importance of various VMS message types in influencing drivers to divert. It also seeks insights on attitudinal differences among different population segments, for more effective use of VMS in on-line traffic operations.

VMS messages are classified into two main categories from the perspective of their utility for drivers: passive and active. A passive message provides descriptive information on the problem that the driver may encounter. It provides information such as the type of the incident, its location and/or expected delay. An active message provides the driver prescriptive route recommendations to avoid the bottleneck, such as the best available alternate route.

A stated preference study is conducted through an on-site survey in the form of a questionnaire. The questionnaire was designed after identifying key factors that influence driver route diversion decisions under VMS. First, the respondents were asked about their socio-economic characteristics including gender, age, education level, and household size. Next, they were asked a series of questions concerning their preferences and attitudes towards traffic information conveyed through a VMS and their propensity to divert under certain situations. The last part of the questionnaire addressed diversion intentions under generic descriptions of VMS messages in terms of the level of detail of information. These messages were specified in a random order to avoid potential directional bias. The responses were recorded on a five point Likert scale (1-5), where 1 meant low willingness to divert and 5 meant high willingness to divert. The survey was conducted in the Borman Expressway region in northwestern Indiana.

The survey results indicate that as information content increases, driver propensity to divert also increases, provided the information type is considered valuable. Messages displaying the 'occurrence of incident' and 'locations of incidents' have similar effects on driver behavior.

‘Expected delay’ and ‘Best detour strategy’ are considered valuable information in terms of influencing drivers’ route diversion decisions.

Using the survey data, a VMS route diversion prediction model was developed to estimate the diversion rate in response to information. A binary logit model formation was used where the choice set of each individual consists of two alternatives – divert or no divert. To translate the Likert scale used in the survey with the binary choice, the actual survey responses are grouped in two ways to obtain the dependent variable for model estimation. In the first method, respondents who answered 4 or 5 are assumed to divert while the others are assumed unwilling to divert. In the second method, respondents answering 3,4, and 5 are assumed to divert and the rest are assumed unwilling to do so.

As a first step, a general model was estimated with all the survey data. The estimation results suggest that users exhibit an inclination to stay on their current route when they do not have much information on the incident. Sex and age are socioeconomic characteristics that significantly influence the diversion behavior of an individual. The model also suggests that the education level of a driver may be an important factor. Then, an attempt is made to explore the presence of significant differences in response attitudes between truck drivers and other travelers in the Borman Expressway region. To address this, survey data were separated into truck and non-truck observations and separate binary logit models are estimated for them. Another model with the pooled truck or non-truck data and interaction variables were estimated. The strong correlation between VMS message type and driver response in the estimation results suggests message content as an important control variable for improving system performance. Significant differences were found in the attitudes of truck and non-truck drivers.

Peeta, S., and Gedela, S. "Real-Time Variable Message Signs Based Route Guidance Consistent with Driver Behavior." *Transportation Research Board 80th Annual Meeting*.

This research proposes a variable message sign (VMS) control heuristic that is computationally tractable on-line, consistent with driver behavior, responsive to changing traffic conditions, portable and obviates the need for future demand and/or system state predictions. It uses a hybrid combination of off-line and on-line components to determine the diversion rates required to optimize system performance under an incident. It then uses a driver VMS route diversion response behavior model to determine the content of messages to be displayed consistent with the desired diversion rates. Hence, message control is used as a control variable to influence route diversion.

The proposed VMS control heuristic addresses the problem by determining optimal diversion rates for unequipped drivers under current network conditions. The primary objective of the VMS control heuristic is to obtain diversion rates and consequently new path assignment proportions for unequipped drivers whose pre-determined paths (historical paths) include the incident link. The VMS control heuristic ensures that the VMS are inactive when there is no incident/congestion and after the effects of an incident/congestion on the network have dissipated. The control heuristic uses the driver diversion response model to determine the messages to be displayed from the diversion rates obtained. The display locations are determined by comparing diversion rates with threshold activation criteria. Messages are updated based on traffic data feedback. The VMS control heuristic consists of three sub-algorithms that follow a sequential logic to determine: 1) the VMS that should be activated, 2) the messages to be displayed on the active VMS, and 3) the frequency with which the VMS messages should be updated.

The Activation Algorithm: The activation algorithm determines the VMS to be activated for message display (by the message display algorithm) through a set of heuristic rules. These rules activate only those VMS for which the required diversion rates to improve system performance exceed a pre-specified threshold. This implicitly ensures that the sensitivity of the network performance vis-à-vis the diversion achieved by the identified VMS is significant. It eliminates the need to activate VMS which do not significantly influence system performance.

The Message Display Algorithm (MDA): This determines the optimal messages to be displayed on the VMS selected by the activation algorithm using one of two system controller objectives, user equilibrium (UE) or system optimal (SO) flow patterns. A multiple user class deterministic dynamic traffic assignment (DTA) algorithm is used to determine the optimal path assignment proportions under the incident (case 1), based on the objective (UE or SO), for computing the desired diversion rates. The deterministic DTA model calculates the optimal path assignment proportions in a network with multiple user class over a planning horizon of interest. It takes as input deterministic OD desires and an initial path sets for all drivers and determines path assignment proportions that optimize system performance. The optimal assignments are also computed using the actual user class fractions (case 2). The optimal path assignment proportions from the two scenarios are used to determine the messages to be displayed on the VMS. This is done by comparing the path assignment proportions from case 2 with those from case 1. If the proportions are larger in case 2 compared to case 1 for the incident-affected VMS paths, unequipped users could be induced to switch from those paths through appropriate VMS messages.

The Update Frequency Algorithm: The displayed VMS messages need to be updated over time to reflect changes in the incident situation and/or traffic flow conditions. For example, progress in the incident clearance may enable increased capacity on the incident link leading to an increased ability to route traffic through the incident area. Similarly, improved traffic conditions in the vicinity of the incident due to prior VMS messages may require the updating of the messages displayed. The update frequency algorithm determines when such updates should occur, that is when to invoke the MDA. It does so by monitoring at regular intervals the incident clearance situation and the flow conditions in the incident vicinity.

The proposed VMS control heuristic is implemented using a hybrid framework consisting of off-line and on-line components. The off-line component addresses the computationally intensive components and the on-line component uses an efficient rolling horizon implementation that circumvents future state predictions.

Simulation experiments using DYNASMART, a mesoscopic traffic simulator, were conducted to evaluate the performance of the VMS control heuristic and obtain insights on it characteristics. The experiments were conducted using the Borman Expressway corridor network that consists of 197 nodes and 458 links. Several experiments using hypothetical scenarios were simulated to obtain insights on the VMS control heuristic. In all cases, the corresponding system optimal solutions were used as benchmarks to evaluate the effectiveness of the proposed VMS control heuristic.

Polak, J., and Jones, P. (1993). "The Acquisition of Pre-Trip Information: A Stated Preference Approach." *Transportation*, 20(2), 179-198.

The aim of this study was to investigate the potential impacts of the provision of reliable pre-trip information concerning expected travel conditions at different times of day and by different modes, on the behavior of travelers. It was based on the use of a simulation of a dynamic, in-home travel information system. This work was undertaken within the EURONET project, which is part of the first phase of the European Commission's DRIVE program. The study was carried out in parallel in Birmingham and Athens. The research sought to address the questions:

- what pre-trip information do travelers want? How much and in what form? What are the patterns of information acquisition?

- how might pre-trip information affect different dimensions of traveler behavior?

The study was concerned with an in-home system giving information about expected travel conditions to the city center, at different times of day, both by bus and by car.

A pilot exercise was conducted where a rudimentary pen-and-paper simulation of the in-home, pre-trip information system was developed. The pilot work made it clear that travelers had different information requirements in terms of both the type and presentation of pre-trip information. There was also varying attitude concerning the scope of the information required with some respondents indicating the desirability for the system to include information on the time it would take to find a parking space and to take explicit account of bus frequencies and timetables. The pilot also established that it would be necessary to demonstrate the information system to respondents, so that they could become accustomed to the idea of interrogating the database, and considering a range of travel options, which for most was an unfamiliar concept. Based on the result of the pilot exercise, it was decided not to attempt to include any route specific information in the final computer-based simulation used for the in-home part of the study.

In line with the findings from the pilot exercise, the final version of the simulation had the following capabilities:

- it provided information on expected network travel times by bus and car at different times of the day;

- in the case of car, information was also provided on expected parking search times in the city center;

- a rudimentary public transport timetable was also included enabling the system to present information concerning the expected arrival time of buses at stops; and

- respondents were able to enquire about either 1) the expected travel conditions associated with a particular departure time, or 2) given these travel conditions, at what time they must depart in order to arrive at their destination by a certain deadline.

Since the ranking exercise that followed the enquiry phase was only meaningful in the case of two or more options, respondents were always required to make at least two enquiries for each simulated day. Respondents were allowed to repeat the process of enquiry and ranking on up to five successive simulated days. The in-home exercise was preceded by the non-home SP exercise, which usefully served to familiarize the respondent with the form of the interview and, in particular, the ranking exercise.

The study has provided a number of important insights into the factors influencing travelers' likely use and response to home-based pre-trip information systems. In terms of information requirements, the results indicate that even among regular car users in Birmingham and Athens, there is a requirement for multi-modal pre-trip travel information. The results suggest that there is considerable scope for the enhancement of the current generation of pre-trip information systems, which largely offer only uni-modal information. The findings also suggest that the quantity and type of pre-trip information requested by travelers depend on a range of personal, journey related, contextual and national factors. This implies that pan-European pre-trip information technologies must be sufficiently flexible in their design to allow a range of different modes of enquiry corresponding to travelers' particular requirements and to differences in national conditions. Although travelers showed considerable interest in the use of pre-trip information, there is evidence that they are selective in the amount and type of information that they request and that the process of information acquisition is structured according to travel preferences. Finally, the results have highlighted significant differences between Birmingham and Athens in terms of travelers' capability and inclination to modify their travel behavior at the pre-trip stage.

Polydoropoulou, A., and Ben-Akiva, M. (1999). "The Effect of Advanced Traveller Information Systems (ATIS) on Travellers' Behaviour." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 317-352.

Khattak, A. J., Polydoropoulou, A., and Ben-Akiva, M. (1996). "Modeling Revealed and Stated Pretrip Travel Response to Advanced Traveler Information Systems." *Transportation Research Record*, 1537, 46-54.

Polydoropoulou, A., Ben-Akiva, M., Khattak, A. J., and Lauprete, G. (1996). "Modeling Revealed and Stated En-Route Travel Response to Advanced Traveler Information Systems." *Transportation Research Record*, 1537, 38-45.

Polydoropoulou, A., and Ben-Akiva, M. "Case Studies of Users' Response to Advanced Traveler Information Systems (ATIS)." *3rd Annual World Congess on Intelligent Transport Systems*, Orlando, Florida.

Polydoropoulou, A., Gopinath, D. A., and Ben-Akiva, M. (1997). "Willingness to Pay for Advanced Traveler Information Systems: SmarTraveler Case Study." *Transportation Research Record*, 1588, 1-9.

Polydoropoulou, A. (1997). "Modeling User Response to Advanced Traveler Information Systems (ATIS)," Ph.D. thesis, Massachusetts Institute of Technology.

The first paper summarizes work by Polydoropoulou and co-workers in the area of traveler response to ATIS.

A general framework for modeling the adoption and use of ATIS products and services is hypothesized to consist of six partially interrelated stages:

- awareness: this relates to the potential user's level of knowledge and perceptions about ATIS services and their attributes. The likelihood of a traveler being aware of a specific ATIS service depends on information needs and availability;

- consideration set formation: this relates to the potential user's decision to place ATIS in a new mental category or to consider it together with other travel services. This will depend on awareness of ATIS options, perceptions of attributes or benefits, and experience with other travel products;

- choice set formation: this reflects the traveler's *potential* set of solutions in response to an identified travel need. Relevant factors include travel patterns, perceived travel needs, cost and method of payment, and perceived benefits;

- trial use: this refers to the decision of a traveler to use ATIS for a particular trip;

- repeat use: this refers to a traveler's assimilation of ATIS products into continued or habitual travel behavior. After trial use, the traveler may become satisfied that the ATIS product meets a perceived travel need, and would then continue using it; and

- travel response: this relates to the behavioral responses of the ATIS user and the extent to which ATIS systems affect trip-making behavior. In general, pre-trip messages received from an ATIS may affect the decision to travel or not, and the choices of destination, mode, departure time, route, and parking location. En route messages received from an ATIS may affect the decision to continue with the pre-trip choices, or to switch the destination, mode, route, or parking location. These decisions will also be affected by the traffic conditions observed while en route up to the decision point.

The interrelations between these different stages are due to learning. System learning provides feedback which transfers information back to the market response process, typically as a result of the trial usage experience. Trip learning via repeat use of an ATIS product involves (i) the adjustments that travelers make in their trip decisions in order to best utilize the information provided by an ATIS; and (ii) the possible decision over time by travelers to modify their ATIS usage characteristics or to consider other ATIS options.

The authors argue that complete and accurate assessment of ATIS impacts requires development of a comprehensive model system representing all the stages identified above. However, estimation of such a model system would require a data set providing information on all these stages of travelers' responses, and such a data set does not currently exist. Accordingly, the authors develop, using different data sets, two separate case study models that cover the market-related and travel-related components of the overall framework. The model of market-related components examines the market penetration of a specific ATIS offering (SmarTraveler) using data from a test market. The model of travel-related components treats travelers' response to different kinds of ATIS using SP survey data from the Golden Gate Bridge corridor in the San Francisco Bay area. Dynamic aspects of behavior (learning and the day-to-day evolution of usage patterns) are not treated.

The market response case study is based on SmarTraveler, an ATIS operating in the Boston metropolitan area that provides real-time, location specific, multimodal (traffic and transit) information to travelers by telephone. Survey data was collected from a random sample of the system's target population (people aged 17 or more who use major highways within the SmarTraveler service area). Questions related to travel and socio-economics characteristics, usage of conventional traffic information sources, awareness of SmarTraveler, and perceptions and attitudes towards different traffic information sources. SP data on willingness to pay for traffic information was also collected.

The system of integrated models developed in (Polydoropoulou 1997) from this data captures ATIS market penetration and usage rates. It predicts traveler's awareness, trial use, repeat use of, and willingness to pay for SmarTraveler.

Awareness is modeled as a function of travelers' need for traffic information, a latent variable which is indicated by the importance travelers place on traffic information attributes such as reliability and relevance, among other influences.

Trial use is a function of the level of knowledge about how to access and use SmarTraveler, and of the importance of traffic information to travelers. Both of these are latent factors, indicated by respondents' answers to different survey questions. The latent factors determine the utility of trial use.

Repeat use is modeled as a function of the relative advantage of SmarTraveler over other traffic information sources, and of the perceived quality of the information that it provides. Again, these are latent factors indicated by survey responses and influenced by traveler's socio-economic characteristics, travel patterns, and consultation of different information sources.

The model of willingness to pay predicts consumers' frequency of use under different pricing scenarios, including a flat monthly rate and a pay per usage plan; separate models are estimated for current SmarTraveler users (a usage rate model) and for non-users (a willingness to pay model). The usage rate is modeled as a function of pricing scenarios and individuals' travel and socio-economic characteristics, as well as latent attitudes towards and perceptions of ATIS. The willingness to pay is affected by the expected benefit from ATIS, a latent variable indicated via the importance placed on ATIS attributes such as reliability and coverage.

The travel response case study is based on data collected at the Golden Gate Bridge corridor. Models of pre-trip and en route response to traffic information were developed (see (Khattak, Polydoropoulou et al. 1996) and (Polydoropoulou, Ben-Akiva et al. 1996)). The models were estimated using combined RP and SP data, and predict traveler response to different types of ATIS messages. In the case of pre-trip information, for example, the different types of messages included qualitative information; quantitative information on prevailing conditions; quantitative information on predicted conditions; prescriptive route recommendations; and prescriptive mode recommendations. The possible responses to these messages included decisions to cancel the trip, to leave earlier, or to choose a non-habitual route or mode. The en route traveler response model involved the decision to switch to an alternate route.

The paper concludes with a synthesis of some conclusions that the authors reached with respect to the ATIS user adoption process (including awareness, trial use and repeat use); travelers' willingness to pay for ATIS; and traveler response to ATIS messages.

With respect to the user adoption process, the awareness phase is influenced by marketing efforts and effectiveness. Cell phone ownership (recall that SmarTraveler is a phone-in service) and income positively influence awareness. Those who have already shown an interest in available traffic information sources are more likely than other people to be aware of new ATIS products; however, this effect is marginal compared to the impacts of a marketing campaign. People who place a high importance on traffic information quality (accuracy, coverage, timeliness) are more likely to be aware of new ATIS products.

With respect to trial use, individuals who place high importance on traffic information quality are more likely to try a new ATIS product, and trial use is also strongly affected by ATIS advertisements and promotions – in the particular case of SmarTraveler, by television exposure.

With respect to repeat use, the likelihood of becoming a confirmed user depends on the perceived advantage of using the ATIS product relative to other available products. In the case of SmarTraveler, the product was viewed by its users as complementary to other traffic information sources, and not necessarily consulted on a regular basis. Factors that were found to lead to increased access levels by repeat users included extreme weather conditions, awareness (from other sources) of a traffic accident, and situations where on-time arrival at the destination is important. In a related consideration, the perceived quality of the ATIS messages significantly affects the willingness to adopt SmarTraveler.

With respect to willingness to pay, the authors point out that their models account for possible response bias and are sensitive to different service payment options. In general, willingness to pay is influenced by message quality and, to a lesser extent, by travelers' perceptions of and attitudes towards travel information. The authors develop usage demand curves for the SmarTraveler system. For pay-per-access options, a charge of 10 cents per access results in a demand for 2.5 accesses per week by non-users and 3.5 per week by users. The unit-elastic price is 50 cents for users and 40 cents for non-users, corresponding to a demand of one call per week. For flat rate options, a monthly charge of $2.50 results in a probability of subscription by non-users of 28% and by users of 42%. The unit-elastic price is $12/month for non-users and $10/month for users, corresponding to a 10% probability of subscription. However, the authors warn that the results, while not unreasonable, should be treated with caution. They note that a great deal of variability is found in willingness to pay figures from different studies, so the reliability of the results is questionable.

Turning to the issue of traveler response to ATIS services, the authors consider separately pre-trip and en route response.

With respect to pre-trip response, increasing levels of expected delay result in decreasing probability that habitual travel decisions will be maintained. Qualitative information increases the likelihood of leaving earlier and of switching from the habitual route. Quantitative and predictive information favor changes in departure time. Prescriptive recommendations to switch routes have an effect on that behavior, but almost none on changing mode or departure time. Prescriptive recommendations to take public transport also have some effect on mode and later departure time, but almost none on changing routes or leaving earlier. In qualitative terms, it is concluded that prescriptive guidance in situations of unexpected delay does have a strong influence.

With respect to en route response, conventional traffic information sources are frequently unable to overcome travelers' reluctance to change earlier decisions; however, ATIS messages are more effective in producing this effect. The more elaborate the information on delay on the usual route, the more likely it is that travelers will switch to an alternate route. Currently available modeling results are not conclusive about the effects of different types of ATIS in influencing en route behavior.

Proussaloglou, K. E., Haskell, K., Vaidya, R. L., and Ben-Akiva, M. (2001) "An Attitudinal Market Segmentation Approach to Commuter Mode Choice and Transit Service Design." *Transportation Research Board 80th Annual Meeting*.

This paper reports the estimation, interpretation, and application of a market segmentation and choice modeling study undertaken for the San Diego Metropolitan Transit Development Board (MTDB). The objective was to assess the competitive positioning of transit in order to support TransitWorks, the Board's strategic planning effort, by evaluating options for the expansion of transit service.

Data was collected on transit users' socioeconomic characteristics, attitudes towards everyday travel, preferences towards different types of transit service, current travel and mode choice behavior, and tradeoffs among a range of transit and highway service attributes using a combined telephone and mail survey in the San Diego area.

Travelers' attitudes were used to identify important dimensions of everyday travel and develop six distinct market segments representing different types of urban travelers. The segments were formed based on travelers' responses to attitudinal statements about everyday travel and their choice behavior. Factor analysis revealed the presence of eight significant factors in the data: need for flexibility and speed, sensitivity to personal travel experience, sensitivity to personal safety, concern for the natural environment, sensitivity to use of time, sensitivity to transportation costs, sensitivity to crowds, and sensitivity to stress.

These factors were used as a basis for segmenting the market: respondents' scores with respect to the different factors were computed, and cluster analysis was used to identify groups of respondents having similar scores. The analysis found that differences between different clusters could best be explained by the factors relating to the need for flexibility and speed, the sensitivity to personal travel experience, and the sensitivity to personal safety. The first step in segmenting the market was to divide the respondents into two groups based on their need for flexibility and speed. Those with a low need for these were further subdivided into two smaller groups based on their degree of sensitivity to personal travel experience. Those with a high need for flexibility and speed were also subdivided into three groups based on their sensitivity to personal travel experience. Finally, the group of respondents with medium sensitivity to personal travel experience was subdivided one more resulting in two smaller groups, distinguished on the basis of their attitude towards personal safety. The resulting market segments were given names indicative of their attitudes

Next, an extensive analysis of the choice behavior of each market segment was undertaken using stated preference methods in which travelers are asked to chose among different transit and highway travel options to explore differences in their sensitivity to different aspects of transit and highway service. Insights into travelers' tradeoffs were obtained from the econometric analysis of the choice experiments using multinomial logit models. Differences in the relative importance of the determinants of mode choice behavior were identified and quantified to reveal important differences among segments of the market.

The findings from the market segmentation and choice analysis were combined with a region-wide survey and the origin-destination (O-D) trip matrices from the regional travel model of the San Diego Association of Governments to quantify the travel patterns in the study area. These insights are currently used to support the comparative evaluation of different types of transit service along different corridors aimed at distinct segments of the market

Ratcliffe, E. P. (1972). "A Comparison of Drivers' Route Choice Criteria and Those Used in Current Assignment Processes." *Traffic Engineering and Control*, 13, 526-529.

Huchingson, R. D., McNees, R. W., and Dudek, C. L. (1977). "Survey of Motorist Route-Selection Criteria." *Transportation Research Record*, 643, 45-48.

In the traffic assignment models, drivers are generally assumed to choose the route with minimum trip time or generalized cost. This paper, which summarizes a study of home-based work trips by private car drivers, compared the drivers' chosen routes with optimum routes determined using a number of different route choice criteria, including time, cost and others.

The study was carried out at the University of Newcastle-upon-Tyne. A comprehensive questionnaire was sent to each car driver within the employment center requesting details of his/her routes to and from work, and reasons why he/she chose their particular routes. A total of 881 usable replies were collected.

The route choice criteria considered in the determination of optimum routes were: (i) trip time; (ii) trip distance; (iii) trip cost (total or perceived); (iv) congestion measured in two different ways: by the ratio of the extra time spent on a link due to congestion to the total congested time spent on the link (factor A), or by the trip time at the desired speed plus a time penalty due to congestion (factor B).

The results show that minimization of congestion factor A does not replicate actual route choices. The probable reason for this is that it is difficult for drivers to differentiate between small changes in congestion. Congestion factor B, which is more closely related to direct journey time measurement, is less sensitive in this way and displays a degree of accuracy similar to the remaining criteria. If single path (all or nothing) assignment techniques are utilized and all trips are assigned to the minimum routes, between 46 to 56 percent of routes will be correctly predicted depending upon the criterion selected, the most accurate being perceived cost and the least accurate trip time and factor B. More results are presented in the paper.

The paper by Huchingson, McNees and Dedek is very similar to the Ratcliffe paper described above. Both of them deal with route choice criteria of motorists. The only substantial differences concern the experimental setup and data collection and survey location and procedures.

Rilett, L. R., and van Aerde, M. W. "Routing Based on Anticipated Travel Times." *2nd International Conference on the Application of Advanced Technologies in Transportation Engineering*, Minneapolis, Minnesota, 183-187.

Rilett, L. R., and van Aerde, M. W. (1991). "Modeling Distributed Real-Time Route Guidance Strategies in a Traffic Network That Exhibits the Braess Paradox." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 577-587.

The brief paper (Rilett and van Aerde 1991b) argues in favor of routing based on anticipated (predicted) travel times. It considers a simple network for which dynamic user equilibrium can be solved and shows that anticipatory routing is necessary to obtain dynamic equilibrium conditions.

These results are then (approximately) replicated using the INTEGRATION traffic simulation system. (The approximation results from the stochasticity produced when INTEGRATION applies path choice probabilities at the level of individual vehicles rather than to a large homogeneous population of vehicles.) INTEGRATION includes several vehicle classes, one of which makes route choice decisions based on anticipated future traffic conditions within a dynamic user equilibrium framework. The paper presents simulation study results that show the variation in total system travel time as a function of the fraction of vehicles in this class.

Finally, the paper concludes that multi-path guidance routing strategies will be required to maintain the traffic flow pattern in dynamic equilibrium when large fractions of the vehicle population receive anticipatory guidance.

(Rilett and van Aerde 1991a) discusses a further analysis using the INTEGRATION model. It illustrates the potential occurrence of a dynamic version of Braess' paradox, in which the addition of a link can result in a net increase in system-wide travel time. Whereas the original Braess paradox considered the physical construction of a new link, the authors here consider the addition of a new link to the network database used to guidance generation. They show that such an addition, seemingly innocuous, can cause a similar phenomenon to occur at certain demand levels.

The authors also investigate the effectiveness of decentralized routing computed by in-vehicle guidance devices using data provided from a traffic center, and conclude that either user- or system-optimal flow patterns can be very closely attained in this way; thus, on this basis either a centralized or decentralized architecture may be preferred.

Finally, the authors note that guided vehicles receiving identical information may form platoons that lead to traffic flow inefficiencies. This can be eliminated by introducing small amounts of noise into the routing computation and so directing some vehicles to slightly inferior paths.

Schofer, J. L., Khattak, A. J., and Koppelman, F. S. (1993). "Behavioral Issues in the Design and Evaluation of Advanced Traveler Information Systems." *Transportation Research C*, 1(2), 107-117.

This paper explores key behavioral issues important to understanding traveler reactions to in-vehicle traffic information systems and provides a very useful overview and summary of the main issues and approaches, with reference to on-going work in the early 1990s.

It begins with a general discussion of travel behavior and information. This is followed by a discussion of factors affecting traveler response to ATIS, mentioning issues of information content, type, format, and attributes.

Next there is a discussion of evaluation issues. Methods for studying traveler response to ATIS systems and attributes are discussed, including both stated preferences and revealed preference (observational) studies in laboratory or field settings. Issues in choosing an experimental site for field studies, and in selecting test subjects for driver studies are discussed. Finally, the paper discusses issues related to the measurement of traveler response to ATIS. Questions covered include whether or not travelers use ATIS; how and when they use it; why they use it; how do they perceive ATIS; and what are the consequences of using ATIS.

Schouten, W. J. J. P., van Lieshout, M. J., Spit, W. F. M., and van Eeden, P. G. M. A. "Strategy Development: Balancing Strengths and Weaknesses of Variable Messages Signs." *8th IFAC Symposium on Transportation Systems*, Chania, Greece, 749-754.

Traffic management around the Amsterdam Ring-Road is performed with a combination of variable message sign (VMS) and ramp metering. By providing real-time information on the VMS of queue lengths at bottlenecks on two alternative routes, the route choice of road users are influenced. The information as shown on a VMS has to fit in the general policy on the provision of traffic information without affecting the positive role VMS plays in traffic management. Therefore, an information strategy for VMS that balances both the traffic information and the traffic management aspects has to be developed. As part of a study on the use of travel time information on VMS, the Ministry of Transport has put a major effort into the development of a general strategy on information on VMS. This strategy will form the basis for further development of implementation schemes, text strategies and pilot projects. In this paper the following items are presented – the role of VMS in the Dutch transport policy, research methods, study results, travel times on VMS.

One of the major problems to overcome in successfully introducing such an extensive VMS based information system, is the design of clear, simple, easy to understand, and comprehensive information strategies. To make maximal use of the dynamic nature of VMS and serve both the traffic management and travel information goals, a general information strategy is needed. A general information strategy for VMS was developed in six step process: desk research, consultation of experts, consultation of road users, concept strategy, second expert meeting, strategy. In the desk research the existing knowledge about VMS and the existing practice were investigated. The results of the desk research were used to consult experts and road users on a number of specific questions that were left unresolved in the previous step. The results of the consultations were used to draft concept strategies for the provision of information in general, and the use of VMS specifically. In a second meeting the experts reflected on the concepts. Finally, the information strategy for VMS was formulated.

The definition of the primary function of VMS was used as a starting point in formulating the general strategy. Information has impact on one of the following three components of the driving task: 1) strategic: mode choice, departure time choice; 2) tactical: route choice, driving attitude; 3) operational: speed control, lane usage. Texts on VMS should be aimed at a specific target group and should contain information that influences the driving task mainly on a tactical level. VMS should not be used to display information that needs an immediate response by the motorist. Such information – needed in circumstances such as lane-closures – can be provided better and more safely by lane access control systems.

The experts stressed the importance of developing text strategies for VMS that use travel times. This fits in the policy of stimulating the traveler to evaluate travel mode and route choice using travel times. A first pilot providing travel times was set up at the end of 1996. A larger pilot providing travel times was set up in 1997. The now existing general strategy will ensure that a text strategy based on travel time will be developed in an effective manner. The consultations of both road users and experts will have positive effects on the quality of the pilot.

Shirazi, E., Anderson, S., and Stesney, J. (1988). "Commuters' Attitudes Toward Traffic Information Systems and Route Diversion." *Transportation Research Record*, 1168, 9-15.

From the abstract:

"This report describes the findings of the Los Angeles County Transportation Commission (LACTC) commuter information survey conducted by Commuter Transportation Services, Inc. in February 1987. Commuters in the Los Angeles area were surveyed by telephone to identify how various forms of traffic information are currently used and to assess their attitudes toward diverting from the freeway with improved traffic reporting. The survey collected information on commuter characteristics, factors affecting route change, and commuters' attitudes toward improved traffic information. The survey evaluated three types of traffic information. These included continuous radio reporting, electronic freeway message signing, and a traffic information telephone number."

Survey results showed that a large majority of respondents knew alternatives routes to work. Factors increasing the probability of an en route shift were radio traffic reports, personal experience (particularly driving in stop-and-go traffic), and on-time arrival requirements.

Nearly 70% of respondents indicated that they would divert from their current freeway route if they had accurate information on times and traffic conditions of alternative routes, including via surface streets.

Respondents wanted timely and accurate traffic information (27%), more frequent reporting (15%), and better use of VMS (8%). Responses were favorable towards the idea of continuous radio traffic reporting (68%) and a telephone traffic information number (53%).

Small, K.A., R. Noland, X. Chu, and D. Lewis, *Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation*. 1999, National Cooperative Highway Research Program.

This report addresses two questions regarding travel time evaluation. The first is whether time (and hence time savings) in congested conditions (LOS E or F) is perceived by travelers and freight carriers as being more valuable than time in uncongested conditions. The second is whether, independently of the possible effects of congestion on time valuation, travel time reliability is valued by travelers and freight carriers. An affirmative answer to these two questions would imply that the evaluation of time in congested conditions should account for both the higher unit value of time spent in these conditions, and the greater unreliability of travel time in congestion. Most current evaluation methods do not account for either of these factors; they apply an identical unit time value to travel time under any conditions, and do not consider travel time reliability.

To investigate these questions, the authors carried out a series of stated preference surveys of travelers and freight carriers. The traveler survey concentrated on tripmakers in the California SR 91 corridor. The stated preference questionnaire asked people to make choices in hypothetical tripmaking situations involving tradeoffs between different travel time, costs and degrees of travel-time predictability. (Predictability was quantified by the arrival times that might occur on different travel days.) Logit-form models were then developed from the survey results. Values of travel time and travel time predictability were obtained as the marginal rates of substitution (i.e., the ratios of the coefficients of time or predictability to cost in the linear systematic utility function specifications).

Regarding the effect of congestion on travelers' value of travel time, the most satisfactory model included as explanatory variables the total travel time, the fraction of trip time spent in congested conditions, the income of the traveler, and the monetary cost of the trip. Coefficients of the estimated model were significant and had the appropriate sign. Values of time were in the range of commonly reported values, although perhaps at the low end of the range. The model results imply that the value of travel time is significantly affected by the presence of congested conditions: one hour of travel time in uncongested conditions is valued less highly than one hour in congested conditions. However, the size of this effect depends on additional factors such as the total trip duration and the traveler's household income.

Regarding the value that travelers place on travel time reliability, the stated preference surveys clearly showed that reliability, measured by the standard deviation of travel times, is significantly valued. The work illuminated differences in the valuation of reliability among different income groups and for different trip purposes. Further investigation showed that the value of travel time reliability could be adequately explained in terms of scheduling costs – the cost to the traveler of a late or an early arrival, compared to the intended arrival time.

The travel time and time reliability sensitivity of freight carriers were analyzed using similar stated preference survey-based approaches. However, the results obtained for freight carriers were less robust, in part because of the small sample (20 firms) of carriers that was surveyed, and in part because of survey methodology and analysis difficulties: carriers' trip decisions are usually made in a more complex context than travelers' decisions, and are correspondingly more difficult to survey and analyze.

It was found that travel time and cost are important factors in freight carriers' trip decisions. Again, time spent traveling in congested conditions was valued more highly than time in uncongested conditions. Late schedule delays (the monetary value of arriving one hour later than scheduled) were valued more than twice as highly as travel time savings; apart from this, travel time reliability was not found to have an intrinsic value to freight carriers per se.

The authors propose to incorporate their results in the standard user-cost analysis framework by applying a mark-up factor of 2.5 to travel time savings that occur under highly congested conditions. This factor accounts both for the higher unit valuation of travel time in such conditions, as well as for the greater likelihood that travel in congestion entails a greater degree of time variability.

Smulders, S. (1990). "Control of Freeway Traffic Flow by Variable Speed Signs." Transportation Research B **24B**(2): 111-132.

This paper considers freeway traffic control by means of variable speed advisory signs. These signs recommend driving speeds to freeway users, but with no obligation on the part of the users to comply – the signs are purely advisory. The recommended speeds displayed on the signs can be changed based on traffic conditions, although the changes from one display to the next cannot be too great to avoid creating potentially dangerous situations as some drivers abruptly adjust their speeds while others do not.

The author notes the difficulty of predicting driver behavior to advisory messages, and highlights the importance of robust traffic control schemes: schemes that do not fail if the assumptions on which they are based are not verified in practice. He proposes a method called *homogenizing control*, which has as its primary objective to reduce the inhomogeneities of the traffic stream, particularly when its volume approaches the capacity of the section on which it is traveling. It has been shown that, near capacity, small disturbances (variations in traffic characteristics) can be amplified; this may finally lead to heavy congestion and stop-and-go conditions. The aim of homogenizing control is to increase the homogeneity of the traffic stream and so reduce the number and effects of such disturbances.

Detailed investigation of actual traffic measurements on Dutch freeways operating with and without advisory speed controls in effect reveals that the improved traffic stability produced by variable speed advisories can be attributed to a reduction in the fraction of small (less than one second) time headways in the left (fast) lane. (It is known that the onset of unstable traffic conditions frequently occurs first in the left lane.) It was found from this investigation that homogenizing control has the following effects on traffic flow conditions:

- it significantly reduces the fraction of small time headways in the left lane, but has no such effect on other lanes;

- it significantly reduces the variance of time headways in the left lane, again with no measurable effect on other lanes;

- it significantly reduces the instability of traffic flow, measured in terms of the number of serious speed drops observed in a traffic stream. The measured decrease was approximately 50%;

- it produces a slight (0-5%) but statistically significant reduction in mean speeds on all lanes;

- it reduces the mean time headway (about 3% on average) in the right (slow) lane; this translates into an equivalent percentage increase in the right lane volume;

- overall, it does not decrease roadway capacity and may in fact increase it slightly (1-2%);

Based on these observations and conclusions, the author developed a mathematical model of freeway traffic flow under the influence of variable speed advisories. The model consists of stochastic differential equations relating traffic density and mean speed; stochastic elements are introduced to represent the natural variability of traffic conditions.

Using this model, he then investigated different control policies to reduce traffic instability at volumes near capacity. The objective was to reduce the probability of the onset of congested conditions over a finite time; if volumes near capacity only occur for a limited time, such policies may actually succeed in preventing congestion in some circumstances.

The control policies initially considered were driven by lane densities, with the control turned on when threshold densities are exceeded and turned off otherwise. Although effective at reducing the probability of the onset of congested conditions, this policy had the undesirable property of frequently switching between on and off (700 times in 30 minutes, in some simulations). This is clearly not acceptable, so the author turned to hysteresis-type control: the control is turned on when a density is greater than a threshold ρ_{ON}, and turned off when the density is less than a different threshold ρ_{OFF}, with $\rho_{OFF} < \rho_{ON}$. This has the effect of reducing the frequency of switching. The author considers a number of forms of hysteresis control for the speed advisory signs, and shows their properties and effectiveness through simulation.

Srinivasan, R., and Jovanis, P. P. (1997). "Effect of In-Vehicle Route Guidance Systems on Driver Workload and Choice of Vehicle Speed: Findings from a Driving Simulator Experiment." Ergonomics and Safety of Intelligent Driver Interfaces: Human Factors in Transportation, Y. I. Noy, ed., Lawrence Erlbaum Associates, 97-114.

Human factors professionals have been concerned about the degree and severity of driver distraction resulting from provision of guidance information in the vehicle. This study explores how the characteristics of route guidance systems affect the attentional demand and efficiency of the driving task. Specifically, this study was conducted to understand how drivers react to complex route guidance systems under varying task demands resulting from driving in different types of roads. There are three primary issues that motivate this study: mode of information presentation, information content and format, and location of visual displays.

This research uses a high fidelity driving simulator to collect detailed driving performance data to determine the following:

- do electronic route guidance devices lead to better driving performance compared to paper maps?
- do audio route guidance systems lead to better driving performance and lower workload compared to their visual counterparts and paper maps?
- does a head-up turn-by-turn display in combination with a head-down electronic route map lead to better driving performance and lower workload compared to a head-down electronic route map?

The basic study area was a simulated network with three types of roadway: urban two-lane undivided arterials, urban four-lane undivided arterials and parkways. Four route guidance systems were tested in the simulator –a head-down electronic route map, a paper map, head-up turn-by-turn guidance display with head-down electronic map and voice guidance with head-down electronic map. A variety of performance measures were collected during the study. They were – driving speed, workload, number of navigation errors, reaction times.

The analysis has demonstrated that, for the particular devices tested, driving performance is improved with the electronic devices compared to the paper map. It is also clear that the voice guidance/electronic map is associated with better driving performance compared to the visual electronic devices. Subjects had the highest workloads when using the paper map and the lowest workloads when using the voice guidance/electronic map combination. The paper map was associated with the largest number of navigation errors and the voice guidance/electronic map combination was associated with the least number of errors. Subjects drove fastest with the voice guidance/electronic map combination and slowest with the paper map.

Srinivasan, K., and Mahmassani, H. S. "Modeling Inertia and Compliance Mechanisms in Route Choice Behavior under Real-Time Information." *Transportation Research Board 79th Annual Meeting*.

This paper examines route choice, in the presence of real-time information, as a consequence of two underlying behavioral mechanisms, compliance and inertia. The compliance mechanism reflects the propensity of a user to comply with the information supplied by Advanced Traveler Information Systems (ATIS). The inertial mechanism represents the tendency of a user to continue on his/her current path. In general, the two mechanisms operate simultaneously and, when the recommended path is different from the current path, the observed choice results from a tradeoff between them. (It is of course recognized that other factors and mechanisms may also influence route choice behavior.)

The paper describes route choice experiments carried out using a travel choice simulator based on an underlying dynamic simulation-assignment model. The simulator provides to users ATIS messages consistent with prevailing traffic conditions, and then updates the prevailing conditions based on the users' departure time and route choice decisions made in response to the messages. Several experimental subjects can use the simulator simultaneously. Thus, the generated messages and traffic conditions are not exogenous, but rather result from the collective decisions of all users on the network. (See (Chen and Mahmassani 1993) for further description of the simulator.)

The test network consisted of a simulated commuting corridor consisting of three parallel facilities. There are four crossover locations at which a driver on any facility can divert to either of the alternative facilities; thus, at each such decision point, three possible routes are available. The information provided by the ATIS includes trip times to the destination via the three possible routes at a decision location, congestion levels (indicated by a color code), messages alerting drivers that they are stuck in a queue, and post-trip data on the departure time, arrival time and trip time by the chosen path. For each experiment, the system records the traffic conditions, information provided by the ATIS, and user responses. Runs are made at different network congestion levels. The way in which congestion levels vary from run to run is also controlled: in some cases, the level is chosen randomly for each run (random variation), whereas in others the congestion level is maintained over several runs (sequential variation).

Aggregate analysis of simulation experiment results confirm that the probability of choosing the best path (i.e., the path with minimum time based on the ATIS messages) depends on whether that path is currently being followed or not.

The paper proposes a modeling framework that incorporates inertia and compliance mechanisms as latent utilities that interact additively with path-specific utilities. Inclusion of these latent utilities in a path's total utility depends on whether or not the path is the current path, or the best path, or both. The framework also takes account of correlation between error terms, assumed multivariate normally distributed. The framework leads naturally to the specification of a trinomial (because of the three alternatives at each decision point) probit model.

The empirical results strongly support the simultaneous presence of both these mechanisms in route choice behavior. The results also indicate that information quality, network loading and day-to-day evolution, level-of-service measures, and drivers' prior experience are significant determinants of route choice through the inertial and compliance mechanisms. Inertial propensity decreases with increasing congestion and with decreasing information quality. Compliance propensity increases with increased travel time savings and information quality.

Srinivasan, K., and Mahmassani, H. S. "Analyzing Heterogeneity and Unobserved Structural Effects in Route-Switching Behavior under ATIS: A Dynamic Kernel Logit (DKL) Formulation." *Transportation Research Board 79th Annual Meeting*.

This paper uses interactive simulator experiments to investigate dynamic (within a given day and day-to-day) route switching behavior in the presence of information. The dynamic context of route switching includes repeated measurements, heterogeneity, within-day and day-to-day influences of variables, and state dependence effects. The multinomial probit framework (MNP), though well suited to tackle these challenges in dynamic models with a few periods, is prohibitively expensive for panels of longer duration.

The first objective of the study is to formulate a general framework for modeling dynamic route switching for a large number of decision periods. A dynamic kernel logit model is proposed, that retains the flexibility of probit model, while exploiting to some extent the computational tractability of the logit model. The second objective is to analyze the influence of systematic effects on route-switching behavior under ATIS. The effect of trip maker characteristics, trip characteristics and traffic conditions, experiences in traffic, and attributes of ATIS information are examined in this context. A third but related objective is to investigate heterogeneity effects in route switching behavior. In general, differences in route-switching propensities as well as sensitivity to level-of-service measures and other independent variables may be expected across decision-makers. Finally, time-dependent effects in route switching behavior are examined. First, at the systematic level, the influence of prior experiences on current behavior is assessed. These dynamic effects are also modeled in the error terms. At the unobserved level, time dependence effects are examined by specifying suitable variance components. The variance-covariance structures are tested for the presence of temporal correlation (both within day and day-to-day), in addition to serial correlation (due to repeated measurements).

These objectives are achieved by conducting interactive experiments using a dynamic travel behavior simulator. In these, commuters' route switching behavior is observed in the presence of ATIS information. The results indicated that user behavior is influenced by the nature, timeliness, and extent and quality of ATIS information. Route switching behavior is also affected by the level-of-service measures on the alternative routes and users' past traffic experiences. The results present evidence of heterogeneity in user behavior in both observed and unobserved components of the utility. Significant dynamic effects are observed in route switching behavior, both within a day and from day-to-day. The results indicate that significant dynamic learning and adjustment processes operate in user behavior.

Srinivasan, K., and Mahmassani, H. S. "Dynamics in Departure Time Choices of Commuters: A Comparison of Alternative Adjustment Mechanisms." *Transportation Research Board 80th Annual Meeting*.

This paper investigates day-to-day dynamics in departure time choice behavior of commuters in the presence of information. The motivation in modeling departure time choice dynamics stems from the following considerations. The departure time decisions of commuters on a given day significantly influence the within-day distribution of traffic, congestion and queuing patterns on the network in the peak period. Accurate models of departure time adjustments can translate into a robust time-dependent OD prediction capability that is an essential component of dynamic traffic modeling and assignment techniques. In addition, since departure time variations influence the network flow evolution from day-to-day, models of departure time choice dynamics are important for characterizing and analyzing dynamic network states and the associated costs.

Two objectives are addressed in this study. The first objective is to investigate the suitability of alternative behavioral mechanisms of the day-to-day adjustment process in commuter behavior in the presence of real-time information. In particular, the following four heuristic mechanisms are considered: utility maximization among unordered alternatives (multinomial logit), ordinal response mechanism (based on ordered thresholds), sequential greedy search of ordered alternatives and a two stage (nested logit) adjustment mechanism. In pursuing this objective, econometric models of the adjustment mechanisms are proposed and estimated, using data obtained from commuters in an interactive simulator-based experiment. The second objective is to identify key factors influencing departure time adjustment. In particular, the roles in departure time adjustments of system performance measures, users' prior experiences, and real-time information from ATIS are analyzed.

For this study, laboratory experiments are conducted using the multi-user interactive simulator developed at The University of Texas at Austin to examine trip-maker behavior dynamics under real-time information. Based on an underlying traffic simulation assignment model, the simulator provides information to users about the traffic conditions prevailing on the network. The simulation is dynamic and participant's responses are input into the assignment model and directly influence traffic evolution. The simulator's multi-user capabilities allow data collection from several subjects simultaneously as they interact in real-time with the prevailing traffic conditions.

In the experiment, the ATIS supplies information to each trip-maker using three different information strategies. Each strategy consists of a combination of the following three treatments. The first treatment relates to the nature of information and consists of two levels: descriptive and prescriptive information. The second factor is the information type. The six levels considered here include prevailing, predicted, perturbed, differential prevailing, differential predicted and random information. The differences among the levels are primarily based on accuracy, extent and timeliness of supplied information. The third factor, post-trip feedback provided by the ATIS, consists of three levels – feedback on own path, recommended path, and best path.

A comparison of alternative specifications for the departure time adjustment process indicates that the sequential greedy heuristic search process provides a better fit to observed data than the two-stage adjustment model, ordinal response, and utility maximization behavior (over unordered alternatives). This finding implies that a user may undertake a sequence of decisions in arriving at a suitable departure time adjustment as follows. First, he/she decides whether or not to adjust the departure time. Conditional on the decision to switch, other alternatives are evaluated sequentially in about five minute increments. The directionality of adjustment is governed largely by the direction of schedule delay experienced on the preceding day, with an earlier switch following lateness and vice versa. The results illustrate that the observed departure time adjustment behavior is influenced by dynamic transportation system attributes encountered such as trip time variability in the network, trip-makers' short and longer term experiences, and the nature, type and quality of real-time information supplied by ATIS.

Steed, J. L., and Bhat, C. R. "On Modeling Departure Time Choice for Home-Based Social/Recreational and Shopping Trips." *Transportation Research Board 79th Annual Meeting*.

This paper examines the effect of socio-economic characteristics, employment-related attributes, and trip characteristics on departure time choices of individuals. The departure time alternatives are represented by several temporally contiguous discrete time periods such as early morning, a.m. peak, a.m. off-peak, p.m. off-peak, p.m. peak, evening. The focus of this study is on departure time choices for home-based social/recreational trips and shopping trips.

The primary data source used for this analysis is the 1996 activity survey conducted in the Dallas-Fort worth metropolitan area by the North Central Texas Council of Governments (NCTCOG). This survey included an activity diary to be filled out by all members of the household. The activity diary collected information on all activities undertaken during the diary day. The secondary data source for this analysis was a level-of-service (LOS) data file obtained from NCTCOG which provides information on times, costs and distances for travel between zone pairs. The LOS data varies by travel mode (drive alone, shared ride, and transit) and time-of-day (peak and off-peak). The final samples for analysis include 3178 observations for home-based recreational trips and 2056 observations for home-based shopping trips.

Two alternative discrete choice structures were explored. The first is the multinomial logit (MNL) structure and the second is an ordered generalized extreme value (OGEV) structure. The MNL is has the Independent from Irrelevant Alternatives (IIA) property. In the context of departure time modeling, the IIA property implies that there is no increased degree of sensitivity (due to excluded exogenous factors) between adjacent departure time alternatives. The OGEV structure generalizes the MNL structure by allowing an increased degree of sensitivity between adjacent departure time alternatives compared to between non-adjacent departure time alternatives. Thus, it is not limited by the IIA restriction. In the estimations, a preferred model specification based on the MNL structure was developed and then the OGEV structure was tested with this preferred specification. For both recreational and shopping trip categories, the empirical results indicated that the MNL structure is adequate in terms of data fit to represent departure time choice. The dissimilarity parameter in the OGEV model was greater than one, implying inconsistency with utility maximizing behavior. Hence, only the MNL structure was used for this analysis.

Important overall results from the empirical analysis are:

- older individuals are most likely to participate in recreational and shopping activities during mid-day;

- individuals earning high incomes tend to avoid the mid-day periods;
- individuals with very young children (under 5) are unlikely to pursue recreational activities during the p.m. peak and evening;
- individuals with young children (over 5) are likely to pursue recreational activities during the p.m. peak period;
- employed individuals and students are most likely to participate recreational/shopping activities during the later part of the day;
- self-employed individuals are more likely than externally employed individuals to "sandwich" a recreational/shopping activity between the a.m. and the p.m. work periods;
- trips to a recreational/shopping activity from home tend to be made before the evening period;
- trips pursued together with others or by walk are likely to be undertaken during the evening periods; and
- in the current empirical context, the only level-of-service variable that has a significant impact is trip travel time and even this applies only for recreational trips.

Use of departure time choice models such as those estimated in this study is statistically superior to the factoring process commonly used by metropolitan planning organizations to allocate trips to various times of day.

Summala, H., and Hietamaki, J. (1984). "Drivers' Immediate Responses to Traffic Signs." *Ergonomics*, 27(2), 205-216.

From the abstract:

"Earlier studies have shown that when stopped on the road and requested to report a traffic sign which they have just passed, drivers are able to do it correctly more often if the sign is of significance to them. Thus, such a sign is either better detected or better remembered than the less significant ones. In this study, speed changes of 2185 drivers were unobtrusively measured on a steeply rising right-hand bend of a minor road where an experimental sign suddenly came into view. Three signs were randomly alternated, with and without a specific warning flasher: Danger, Children and Speed Limit 30 km/h. It was found that the speed decrement was dependent on the significance of the stimulus sign: the more significant the sign the greater the drivers' immediate response to it. The analysis of speed-change distributions revealed that drivers detected each sign equally well and responded to each by releasing the accelerator, but the responded more strongly to the more significant signs. In the light of these results, earlier findings indicate that significant signs are better remembered by drivers when stopped and interviewed.

"This study, once again, supports the explanation that the problems of the traffic-sign system are mainly due to motivational factors. However, these results also showed perceptual limits in using signs for traffic control: a substantial effect which a specific warning flasher had on the drivers' responses in cloudy and rainy weather and in the dark disappeared in sunny weather indicating that the flasher was not detected against a bright sky."

Thakuriah, P. V., and Sen, A. (1996). "Quality of Information Given by Advanced Traveler Information Systems." *Transportation Research C*, 4(5), 249-266.

This article is concerned with the accuracy of travel time estimates derived from probe vehicles. (Probe vehicles measure their own travel time over a link and transmit this data in real time to a traffic center. Such data can be used as a basis for real-time link travel time estimates.) It uses Monte Carlo simulation to study the effects on the travel time-based information provided by an ATIS of (i) the inherent variability in network flows and travel times due to complex traveler behavior and choices; (ii) partial observation of the network and sparseness of time measurement data during short intervals of time because of limited data gathering opportunities; and (iii) the inability of an ATIS to adequately process and distribute available information in a timely fashion, due to system data processing and communications constraints.

The authors' basic procedure for simulating link travel times is as follows. The time period of interest is first divided into a number of smaller time steps. Network link volumes in each step are simulated based on a statistical model of link flows; the model captures the variability of OD and path flows, as well as correlations between flows on adjacent links in successive time steps. Based on these volumes, vehicle travel times on the links are computed. The travel times of some of the vehicles are then sampled; the number sampled is determined by the fraction of vehicles that are probes. From the resulting sampled vehicle times, an estimate of time-dependent link times is derived, and is then made available in the simulator by means of one of several information provision strategies. Each such strategy applies corrections to the link time estimates to adjust for the sparseness of the sampled data, time lag effects, transmission constraints in distributing information, and so on. The simulation utilizes a 329 link network representing a portion of the road system of northwest Chicago and represents one day. Each experiment involved a series of runs covering 35 simulated days.

Simulations were carried out in a variety of test situations obtained by modifying four distinct experimental design factors: the congestion level (medium and high); the probe vehicle fraction (ten levels ranging from 1% to 100% of the number of vehicles in circulation on the network); the way in which vehicle time observations made progressively during a 15-minute time interval are weighted to obtain a current estimate of link travel time (uniformly; weighting the most recent observations very heavily; and weighting the most recent observations somewhat more heavily than earlier ones); and "message throttling", a strategy in which dynamic travel time estimates are disseminated only if they differ from static times by some specified amount (all dynamic estimates are disseminated; dynamic estimates are disseminated if they differ from static times by one (approximate) standard error; and dynamic estimates are disseminated if they differ from static times by two (approximate) standard errors. (Standard errors are approximate because of the probable presence of correlations in travel times reported by probe vehicles. These were not accounted for in computing the standard errors.) Throttling was originally found to be useful to avoid disseminating large amounts of guidance information (a communications bandwidth issue); in this study it was also investigated as a way to avoid the potentially adverse effects resulting from disseminating high-variance travel time estimates derived from small numbers of probe vehicles.

In general, the authors found that link travel time stochasticity introduced significant complications and counter-intuitive phenomena into the travel time prediction problem. They found that failure to take this stochasticity into account when generating guidance could lead to guidance that was inferior to that obtained from static travel times. However, by appropriately allowing for this stochasticity, substantial travel time savings could be obtained from dynamic guidance messages.

Detailed conclusions depended on the specifics of the investigated problem situation. It was found that with low probe vehicle rates, the variance of basic (i.e. simple average) travel time estimates was so high as to be useless for guidance purposes. The most generally successful strategy at high congestion levels was one which weighted the most recent probe vehicle time measurements somewhat more heavily than earlier ones in estimating travel times; and which only disseminated dynamic times if they differed by one (approximate) standard error from the static value. Route determinations derived from this strategy were frequently close to optimum. At moderate levels of congestion, better results were obtained from a uniform weighting of probe vehicle times, and only disseminating dynamic times if they differed by one approximate standard error from the static value. Note that these two strategies depend on the availability of good quality static link time estimates.

The authors also note that the effectiveness of probe vehicles depends on their dispersal over multiple routes in order that they may obtain as much travel time data as possible. In this regard, probe vehicles may be more effective in conditions of high congestion, where drivers tend to choose a variety of routes in order to avoid becoming stuck in traffic, rather than moderate or low congestion, where a one or a few routes may dominate.

Teng, H. H., Falcocchio, J. C., Lapp, F., Price III, G. A., Prassas, S., and Kolsal, A. "Parking Information and Technology for a Parking Information System." *Transportation Research Board 80th Annual Meeting*.

This article examines technology requirements for parking information systems based on internet access and roadside display. The authors carried out a survey of current users of parking facilities to obtain information about parking user characteristics and their preferences with respect to different types of information system technologies and parking data. The article describes the types of information technology considered . It discusses the analyses that were done of survey responses and the conclusions that were drawn from these.

The authors conducted a mail-back survey of parking garage users at four locations in New York City. The survey response rate was around 3%. The survey questionnaire obtained basic data about the respondent (age, household income, education and gender; knowledge of parking options, propensity to check traffic information before starting a trip) and the trips he or she makes (purposes, frequencies, parking difficulties and search times). The respondents were felt to be representative of potential users of parking information systems.

Next, the questionnaire described different types of data that a parking information system might possibly provide and asked respondents to indicate the types they would be most interested in. The response to each question was related to tripmaker characteristics using a binary logit models; each response was considered as independent of the others. It also asked respondents to indicate their preference from among different access technologies (internet, information kiosk, in-vehicle device); these responses were analyzed with a multinomial logit model. Finally, respondents were asked to rank the importance they assigned to receiving different kinds of data from a parking information variable message sign; these were analyzed using an ordered probit model.

For a parking information web site, the information of greatest interest included fee structure, hours of operation, location, the predicted probability of having a space available at the time of arrival, and traffic conditions in the vicinity of the facility. For roadside displays, the information of greatest interest included hours of operation, number of available spaces, location and fee structure. The estimated models allowed the importance of each of these items to be related to driver and trip characteristics. For example, women respondents were more interested than men in being able to obtain information about facility operating hours.

When a web site, a kiosk and an in-vehicle device were compared for providing pre-trip information, the web site and in-vehicle device were preferred to a kiosk (the cost of such a device was not included as a variable in the analysis). When a variable message sign and an in-vehicle device were compared for providing en route information, the variable messages sign was preferred.

Thill, J.-C. and G. Rogova (2001). Benefits Evaluation of Basic Information Dissemination Services. Transportation Research Board 80th Annual Meeting.

This paper reports on the design and development of a library of modeling tools called "ITS Options Analysis Model" (ITSOAM) to evaluate for NYSDOT the merit of ITS deployment elements within a benefits-cost framework.

ITSOAM is a sketch planning tool intended to assist in the screening of potential ITS deployments. The system is intended for the evaluation of infrastructure-based (rather than in-vehicle) technologies; these include VMS, HAR, non-subscription information services and information kiosks. It is intended for application at the corridor, sub-regional or facility level.

Delay, safety, environmental (emission and fuel consumption) and (in some cases) operational benefits are quantified; no attempt is made to quantify other types of benefit. No account is taken of possible induced demand and temporal or mode shifts resulting from ITS deployments.

ITSOAM accepts as input constant data representing a variety of factors, rates and other assumptions needed to carry out an ITS evaluation. These are key model assumptions such as diversion rates in response to different types of VMS messages. The paper does not describe these assumptions in any detail but notes that the transferability to other locations of the values derived for New York "may be questionable" and suggests sensitivity analyses.

ITSOAM also inputs a technical specification of the particular ITS system to be evaluated. A VMS deployment, for example, is specified in terms of the variety of situations which it will be called on to provide messages about, and the types of messages that may be disseminated in each situation; a set of categories has been defined to characterize different kinds of situation and message.

The article focuses on the calculation of delay, safety and environmental benefits from a VMS deployment.

Delay reduction benefits are quantified in terms of the difference in delays between a baseline and a deployment situation. Delays are computed for a generic corridor topology consisting of a main route and a possible diversion route. Total travel time consists of four components: time spent traversing the main route; time spent in queues behind an incident on the main route; time spent traversing the diversion route; and time spent when traffic on the diversion merges with the main route downstream of an incident. Simple methods are applied to compute each of these values. Again, key parameters such as diversion rates must be provided as inputs to this calculation.

Safety benefits are quantified in terms of the reduction in primary and secondary accidents (including fatalities, injuries and property damage only). Quantities needed to estimate these reductions are derived from the delay model. The predicted number of accidents depends on the accident rate, the duration of a primary accident (for secondary accidents), and the amount of traffic at risk (VMT). The first two factors depend on the level of congestion, while the third factor depends on the amount of diversion to the alternate route. Accident reductions are converted into monetary benefits by applying standard costs. Again, all the key factors and parameters are program inputs.

Environmental benefits consist of reductions in VOC, NOx, CO and fuel consumption. These are obtained by applying standard emissions and fuel consumption factors to predicted speeds and queue lengths obtained from the delay model.

Tsai, J. (1991). "Highway Environment Information Systems Interests and Features Survey." Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS), 113-122.

The paper describes a user interests and features survey undertaken as part of the planning for a commercial vehicle operations (CVO) system in Canada. The planned CVO system built on a project which had introduced satellite-based vehicle messaging and location services for use by the trucking industry. The purpose of the study was to determine the needs of commercial trucks and buses relative to information on the "highway environment" -- traffic, weather, hazards, or other kinds of data which are relevant to the movement planning of commercial vehicles -- as well as to obtain information on the willingness of vehicle operators to pay for such information.

Trucking and busing companies were presented with a list possible advanced information and communication services and asked to rank them. The study found that companies with large truck fleets are more likely to be interested in a highway information service. Companies offering truckload services were more likely to be interested than LTL companies. For-hire and private trucking companies were more likely to be interested than public trucking fleet operators. Inter-city bus companies were also interested.

Additional results elaborated on the specific information features that were felt to be most valuable. These included both traffic and weather information. Included in the traffic information were: information on traffic congestion, accidents, lane closures, bridge closures, construction updates, alternate routes, low bridges, road weight restrictions and legal truck routes. Truckers identified specific areas (generally around the largest metropolitan areas) where such information would be most useful. Weather information needs included: notice of adverse or severe weather conditions, fog conditions, and identification of areas experiencing black ice. When asked about the desired frequency of traffic and weather information updates, some companies replied that it would depend on the time of year and geographical area.

Trucking companies that expressed an interest in improved highway environment information were asked if they would be willing to pay for such information. A small majority answered in the affirmative, but stressed that the price would have to be minimal -- $10-$20/month for all fleet information needs.

Following the survey, a focus group was held with selected trucking company representatives. A number of suggestions were made about useful information features. It was clear that information accuracy and timeliness were important attributes, and concern that too much information might overload drivers or dispatchers, leading to a suggestion that only exception information be provided. Representatives were noncommittal about willingness to pay apart from indicating that the price would have to be commensurate with the benefits provided.

Uchida, T., Y. Iida, et al. (1994). Panel Survey on Drivers' Route Choice Behavior under Travel Time Information. Proceedings of the Conference on Vehicle Navigation and Information Systems (VNIS): 383-388.

This paper describes a panel survey of users of an operational system providing real-time travel time information in Japan. The system displays, using variable message signs, the predicted travel times on three routes that connect the southern suburbs of Osaka to the Osaka CBD. Predictions are derived from real-time measurements of travel time obtained via license plate matching. The observed times are converted into predicted times based on historical relationships. In some cases, traffic counts and speed-density relationships are used as well.

The survey was carried out in six waves in the early 1990s. Its intent was to obtain information on two types of driver reaction:

- tactical reactions: the relationship between the displayed message and the drivers' immediate route choice decision;
- strategic choice: the gradual change in route choice behavior that results from use of the ATIS over time.

Mailback questionnaires were handed out to drivers at traffic lights downstream of the VMS; those who responded were later sent out additional questionnaires regarding their longer-term reactions to the VMS system.

Survey results showed that drivers were interested in and used the travel time information, which they felt was sufficiently accurate for their route choice purposes. Roughly 70% of respondents reported diverting at some time; roughly 15% reported that pre-trip or en route information was the primary basis for diversion. Over time, roughly 40% of respondents reported that they had changed their habitual route as a result of using the ATIS.

Multinomial probit models of tactical and strategic response were estimated from the survey data. The strategic model provided evidence of a strong inertia effect in the selection of a habitual route: drivers had a tendency to continue using the route that they used on prior days; it did not show a significant effect of age, income or other socio-economic variable on the probability of changing habitual route. The tactical model showed a significant effect on route choice of the displayed travel time, and also of the habitual route choice.

van Berkum, E. C., and van der Mede, P. H. J. (1999). "Driver Information and the (De)formation of Habit in Route Choice." Behavioural and Network Impacts of Driver Information Systems, R. Emmerink and P. Nijkamp, eds., Ashgate, 155-179.

van Berkum, E. C., and van der Mede, P. H. J. (1998). "The Impact of Dynamic Traffic Information: Modelling Approach and Empirical Results." Travel Behavior Research: Updating the State of Play, J. Ortuzar, D. Hensher, and S. Jara-Diaz, eds., Pergamon Press, 401-421.

These papers deal with the development of a theoretical and modeling framework that describes the interplay of travelers' knowledge and uncertainty about options and outcomes, learning from experience, formation and deformation of habit, and responses to externally provided information.

An information sensitive dynamic route choice model including habit was proposed. The essential components of the model were:

- select initial values: Any simulation of a day-to-day choice process necessarily starts at a certain point in time. To start the choice process, initial values for the mean expected travel time, travel time variances, strength of habit and credibility of various types of information must be available or assumed;

- perceived utility maximization: To make a choice between alternatives, a choice rule is applied. For environments without exogenous information the model used two rules – perceived utility maximization and habitual choice. If prescriptive information is available, a third choice rule of compliance was applied;

- habitual choice and updating habit: The second choice rule is the habitual choice. Sometimes individuals will not maximize perceived utility but will make a choice based on habit. Habitual choice means that there is a certain probability that the individual chooses a route simply because she has done so before. No comparison of perceived utilities of different options is carried out. Habitual probability increases with the number of times the same route has been chosen before. It decreases with the number of different route choices that have been made since that route was last chosen. The third factor that influences habitual probability is the experienced travel time following from the route choice;

- updating expectations: regardless of the choice rule, individuals learn from their experiences. Learning from experience pertains only to expected utility, because the error term is assumed not to be correlated with experience. After each trip, the experienced travel time is used to update the mean expected travel time and the travel time variance for the chosen route; and

- credibility of information and compliance: Descriptive and prescriptive information influence route choices in different ways. Descriptive information may be incorporated into the perceived utility of alternatives for the subsequent choice. The degree to which this will happen depends on the credibility of the information, while the credibility of information is influenced by previous experiences with the information system. Prescriptive information tells the driver what to do and can overrule perceived utility maximization completely. If so, the individual will comply with the offered advice. Otherwise, the currently operating choice rule will remain valid.

The route choice model was validated for prescriptive and descriptive information. Data from a longitudinal panel study was used for this purpose. The general conclusion from these studies was that learning behavior was a necessary behavioral component of the model framework developed. It showed that it was not valid to assume fixed expectations in day-to-day route choice behavior. The studies also concluded that information induced more learning from the same situation. This means that when information is provided, drivers take the outcomes of their most recent choices more into account, than when no information is provided. If no information is provided, drivers rely more on general expectations based on prior experiences. The research also indicated that habit has a clear functionality in choice behavior – it reduces the task load of drivers and allows them to direct attention to more demanding tasks. Habit may also be an efficient choice strategy when outcomes of options fluctuate strongly, but unpredictably, from day to day.

Vaughn, K. M., Abdel-Aty, M. A., Kitamura, R., Jovanis, P. P., Yang, H., Kroll, N. E. A., Post, R. B., and Oppy, B. (1993). "Experimental Analysis and Modeling of Sequential Route Choice Under an Advanced Traveler Information System in a Simplistic Traffic Network." *Transportation Research Record*, 1408, 75-82.

Vaughn, K. M., Abdel-Aty, M. A., Kitamura, R., and Jovanis, P. P. "Analysis of Sequential Route Choice Under ATIS." *5th International Conference on Computing in Civil and Building Engineering*, 825-832.

These papers perform an experiment to collect sequential route choice data under the influence of an advanced traveler information system using a PC- based simulator. The experiment collected information on drivers' pre-trip route choice behavior at three levels of information accuracy: 60, 75, and 90 percent. An analysis of variance was performed to investigate the interrelationships among the different variables in order to better understand the factors that significantly influence route choice behavior and learning.

The ultimate goal of this research is to develop a realistic model of route choice behavior under the influence of ATIS, which incorporates the effects of drivers' learning abilities. A binary logit model formulation was used for this purpose. In the model formulation, it is assumed that an individual's perceived utility for a specific alternative is a function of the perceived attributes of the alternative, the individual's characteristics, the information available on the alternative, and the perception of the accuracy of such information. There may also be an effect on the perceived utility of an alternative because of a repetitive choice effect: The more times one chooses an alternative the greater its perceived utility may become. This general framework forms the basis for the formulation of specific alternative utility functions within this analysis.

When analyzing sequential choices, the utility functions for each alternative must be updated to reflect the individual's learning processes. Thus, the perceived utility for a specific alternative for a given trial depends on the perceived outcomes of previous trials or experiences. Each sequential choice results in an experience, which in turn influences the next choice. The extent of this influence is affected by the individual's learning ability. Learning abilities are indicated by the speed with which behavior is modified because of new experience, and by the magnitude of the effect of prior experience on current choices.

In the logit model, a route alternative's utility includes alternative specific coefficients, a variable representing the increase in utility of the advised route over the remaining alternative, an experience variable that represents an individual's perception of the delay to be experienced on either the side road or the freeway, another experience variable representing an individual's perception of the accuracy level of the information being provided, and personal attribute variables that the ANOVA indicates have strong effects on the individual's acceptance of advice.

The model estimation results indicate that drivers can rapidly identify the accuracy level of information being provided and that they adjust their behavior accordingly. There is also evidence for the existence of an information accuracy threshold below which drivers will not follow advice and above which drivers readily follow advice. It was found that male subjects agreed with advice more often than females, that less experienced drivers agreed more often than experienced drivers, and that drivers are much more willing to follow advice to take a freeway route. Results also indicated that previous experiences had little effect on current route choices. This may be the result of a mis-specified updating function, indicating further research is required to identify learning relationships.

Wachs, M. (1967). "Relationships Between Drivers' Attitudes Toward Alternate Routes and Driver and Route Characteristics." *Highway Research Record*, 197, 70-87.

Pedersen, D. M. (1998). "Factors in Route Selection." *Perceptual and Motor Skills*, 86(3 (part 1)), 999-1006.

The aim of the (Wachs 1967) study was to determine whether subjective statements made by drivers about their perception of values in a choice between alternative routes for a trip are systematic and consistent functions of the characteristics of the respondents and of the routes about which they respond. If systematic and consistent relationships are found to exist, it is hoped that this study will lead to a better understanding of personal perceptions of benefit, and of how these perceptions differ among people.

For this study, a home interview survey was constructed, tested and revised. Constrained-response type questions were used for the collection of most of the information and to facilitate the quantitative analysis of the data. Twenty pilot interviews were conducted to minimize the bias associated with the constrained-response type questions. During the interview, information was obtained about the factors which the respondent considered important in the choice of routes for a trip to work, a trip to shop for clothing, and a trip to visit a friend. In addition, detailed information about the socio-economic and demographic characteristics of the respondent was obtained. The respondent was also asked to draw, on a map supplied by the interviewer, the routes which he perceived as a possible alternatives for his trip to work. This enabled the gathering of detailed information about the characteristics of these routes which was necessary for the analysis. In examining constrained responses in which people gave reasons for choosing a particular route for a trip, testes were made to determine whether the importance of the various reasons differed with the purpose of the trip.

Because many of the 21 attitudinal measurements may actually be measures of the same or similar underlying values, an attempt was made to reduce this redundancy in the matrix of measurements. In order to accomplish this, a rotated principal component factor analysis was performed on the matrix of scaled responses to the statement about route choice. This technique serves to isolate independent dimensions of attitudes toward route choice. Factor analyses were performed separately on responses about work trips, shopping trips, and visit trips. The factor analysis resulted in the reduction of 21 attitudinal variables for work trips to seven orthogonal factors, which account for 67% of the variance in the original variables.

It is hypothesized that a person’s attitudes toward what is important in the choice of a route are dependent on the characteristics of the person and the nature of the trip, and the characteristics of the alternative routes available. The hypothesis is tested and attempts are made to quantify the functional relationships between the measured attributes and the personal as well as trip characteristics of the respondents in three ways. First, canonical correlation coefficients are computed to test for significant relationships between the attitudes and the socio-economic and demographic characteristics of the respondents. Second, multiple regression is used to express each of the seven attitude factors as a function of the socio-economic, demographic and trip characteristics. Finally, a grouping analysis is performed to determine whether groups of respondents with distinct attitude patterns also display distinct patterns of socio-economic or trip characteristic data.

The canonical correlation coefficients do indicate that there are strong relationships between the sets of variables, that these relationships are statistically significant, and there is reasons to further explore these relationships. Seven regression equations were computed, using each of the seven attitudinal factors as dependent variables. The independent variables used in each equation are the results of several trials in which all variables were at first represented as dummy variables, and then those which displayed a linear relationship with the dependent variable were replaced by the original continuous variables. The final method employed in the examination of the interrelationships between work-trip attitude factors and socio-economic and work-trip characteristic variables was a grouping technique. The respondents were grouped so that those within groups were homogeneous in their attitudinal responses, and so that the groups different in their patterns of attitudinal responses. Then, comparisons were made between the groups in terms of their socio-economic, demographic and work data to see how the attitudinal groupings differed in these characteristics.

The major findings of this study may be summarized as follows:

- people's preferences for various route characteristics vary, and variations can be related to the peoples' characteristics, their trips and the routes to which they have been exposed.

- responses to attitudinal statements about reasons for route choice do not vary greatly with the type of trip.

- factor analysis is a useful method for the reduction of a battery of attitudes about route choice to fewer independent and interpretable dimensions.

- drivers' attitudes toward which factors are important in the choice of a route for the trip to work appear to be strongly influenced by their trip length.

- drivers seem to be able to satisfy their preferences for many route characteristics.

The Pedersen paper (Pedersen 1998) is similar to the paper by Wachs (discussed above) in that both use principal component factor analysis to determine the factors that influence peoples' route choice. Four orthogonal factors involving in selecting automobile routes were obtained:

safety, interest, purpose and hindrances. A profile analysis was also performed to find if these factors were differently rated by men and women.

Wallace, R., and Streff, F. (1993). "Developing Advanced Traveler Information Systems: Considering Drivers' Information Needs." *UMTRI Research Review*, 23(6), 1-13.

This paper reports on a mail survey conducted by UMTRI in order to gather data on Michigan driver information needs and wants and its implications for ATIS design. Three components of the effort concentrated on commuting trips, non-commuting trips in a familiar environment; and trips in an unfamiliar environment. Of roughly 9,000 questionnaires mailed out, and after follow-up reminders, around 2,700 completed surveys were returned.

Questions on map use and way-finding revealed that most respondents use maps relatively infrequently, and that people generally prefer some combination of verbal and written instructions in combination with maps when navigating in an unfamiliar area. This suggests that ATIS functionality will need to encompass more than a visual map display in order to be perceived as useful: zoom capabilities, ability to track vehicle movement, multiple modes of message delivery (audible as well as visual), and incorporation of yellow-page type information might be among such enhancements.

Questions regarding use of non-ATIS traffic information showed that, regardless of trip type, around 40% of drivers consult traffic radio information. More than 30% felt that radio traffic information arrived too late to be useful.

Questions regarding the types of information that are relevant to route choice or route switch decisions revealed broadly similar concerns but some interesting ranking differences between the three trip types considered.

For commute trips, the principal types of information are delay time , delay time predictability and level of congestion on the current route; consequences of late arrival at work; nature of the traffic problem; condition, level of congestion and ease of access to the alternate route; distance to the traffic problem; and travel time on the alternate route.

For driving in a familiar area, the main factors are the condition and level of congestion on the alternate route, the delay time predictability, level of congestion and delay time on the current route; the state of repair of the alternate route; the nature of the traffic problem; ease of access to the alternate route; time of day; and distance to traffic problem.

For driving in an unfamiliar area, the main factors are the condition of, availability of directions for, level of congestion on, state of repair of and ease of access to the alternate route; the level of congestion, delay time and predictability of delay time on the current route; the time of day; and the nature of the traffic problem.

This suggests that an ATIS should be designed to provide a potentially large variety of information types that can be selected by the user depending, for example, on the nature of the trip. For example, in unfamiliar areas way-finding directions (possibly incorporating real-time traffic condition information) would be valuable, whereas in more familiar environments presenting traffic condition data may be most appreciated.

Wardman, M., Bonsall, P., and Shires, J. (1997). "Driver Response to Variable Message Signs: A Stated Preference Investigation." *Transportation Research C*, 5(6), 389-405.

Prior research has suggested that the drivers' responses to traffic information and route advice offered via variable message signs (VMS) are highly dependent on the message content, the driver's network knowledge, and on the extent of any implied diversion. The objectives of the work reported in this paper are: 1) to include a wider range of messages in the traffic information and route advice provided by VMS; 2) to construct explanatory models of drivers' route choice behavior in response to a variety of messages; 3) to explore the factors influencing this response; 4) to draw policy conclusions on the use of VMS to influence drivers' route choice; and 5) to draw conclusions about the data collection and modeling methodology.

The study uses SP techniques in order to evaluate drivers' route choice responses to information on road traffic conditions. An SP approach was adopted in order to be able to determine driver response to a wide range of VMS messages while also excluding unwanted external influences. A revealed preference (RP) survey based on drivers' actual choices would not have been practical because of the high interview costs and the lack of control over the external factors.

The SP exercise was based on a trip of around 34 km from Warrington to Manchester City center. A pictorial representation of the choice context was devised. This comprised a photograph of the approach to the M62/M6 intersection, showing a 'through-the-windshield' view of traffic conditions on the M62 ahead and on the off-ramp leading to M6 and a roadside VMS panel displaying a text message about traffic conditions ahead. This information was in the form of estimated delays on three of the four routes and the causes of those delays. The 'through-the-windshield' information about current traffic conditions at the site was reinforced with a written description.

The SP experiment offered choices between four routes. A multinomial logit model (MNL) was used to analyze route choice probabilities. The main limitation of the MNL model is its independence from irrelevant alternatives (IIA) property, which stems from the assumption that the unobserved influences on choice that are contained in the model's error term have a common variance and are uncorrelated across alternatives. As a result, for example, an increase in delays on the M62 will be forecast to increase demand on each of the other three routes by the same proportionate amount. The most straightforward means of allowing for possible different rates of substitutability between travel alternatives is to use a nested logit model. One nested structure in which the two A types of roads were combined in a lower nest was found to be statistically superior to the MNL model according to a likelihood ratio test. However, given the nested model performed only marginally better and that its logsum parameter of 0.8 is little different to the value of 1 which causes a nested model to collapse to the MNL form, it was decided instead to simply proceed with the simpler MNL model.

The results show that route choice can be strongly influenced by the provision at appropriate points of information on traffic conditions ahead. Additional delays mentioned on the VMS panel have been found to be valued more highly than normally expected travel time with ratios. The high value presumably reflects the greater stress, frustration and unreliability of driving conditions where delays are present. The value of delays increases with the size of the delay. Qualitative descriptions of delays were found to have an appreciable impact on route choice. It was found that different stated causes of delay had different impacts. Delays attributed to accidents had the biggest impacts on route choice. This seems plausible given the high level of uncertainty that inherently surrounds accidents. Visible queues were found to have a significant effect on route choice.

The results have suggested that traffic information shown on VMS can significantly affect drivers' route choice and that the scale of the effect is dependent on the content of the message, local circumstances, drivers' characteristics. The fact that drivers' responses are influenced by whether or not the cause of delays is explicitly stated is a very useful finding which could be employed to influence the amount of diversion upwards or downwards in the interests of optimizing flow levels on different links. It should be also noted that a blank VMS screen is interpreted differently from a positive 'all clear' message and that there is some evidence to suggest that drivers may be second guessing the motives of those who control the messages.

Watling, D., and van Vuren, T. (1993). "The Modeling of Dynamic Route Guidance Systems." *Transportation Research C*, 1(2), 159-182.

The intent of this paper is to identify some of the important issues involved in developing models of dynamic route guidance systems – systems that provide drivers with messages, based on real-time measurements of traffic conditions, intended to assist in their route choice decisions. It is based on published literature and operational systems as of the early 1990s, although the many points that it makes regarding modeling needs and options remain valid (and sometimes still unrecognized in ongoing efforts) today.

The authors suggest that a guidance system model should consist of three distinct but closely interacting elements:

- a model of driver behavior, that represents the tripmaking decisions of unguided and guided drivers to network conditions and (in the latter case) to guidance messages;

- a model of the traffic network, representing the topology and operational characteristics of the network (both links and intersections), the capable of predicting the service characteristics that vehicles will experience when traveling over it; and

- a model of the control system, meaning the data collection, communications, information processing and guidance generation components of the guidance system.

Regarding the control element, the paper identifies and discusses a number of aspects that may be relevant for realistic modeling of a guidance system. These include: accurate representation of the data collection and transmission technologies; capabilities for predicting trip times; representation of guidance message characteristics such as their content, format and update frequency; specific modeling of differences between pre-trip and en route guidance; recognition of different possible guidance strategies and approaches that may be pursued by a guidance control center, including in particular the dissemination of single- or multiple-route guidance when large fractions of drivers are guided; and integration of the route guidance system with other traffic management components including signal control, electronic road pricing, and transit and parking information systems.

Regarding the network modeling element, the paper argues that static models are inadequate to represent short-term changes in traffic conditions that a route guidance system is intended to compensate for: therefore route guidance system modeling requires dynamic network models – that is, models in which the important variables such as OD demand rates, path flows and costs, and link flows and costs are time-dependent. Similarly, it argues that the dynamic model should be able to represent the variability in traffic conditions, resulting either from random between-day variations in travel demand or network supply characteristics, or from specific causes such as incidents. The paper discusses the appropriate choice of the physical network represented by the model: the set of links referred to in guidance messages (either as path recommendations or by having condition information provided) may well be a subset of the set of physical links actually making up a road network, in order to avoid routing drivers to local streets or through sensitive areas (near hospitals, schools, etc.) The link and intersection performance models must be able to adequately represent congested conditions and the effects that contribute significantly to them (e.g., turning movements across opposing traffic and traffic signal settings).

With regard to the driver behavior element, the authors first point out the need to be able to represent the behavior of unguided drivers as well as guided drivers. They contrast two extreme assumptions: that the presence of a guidance system (and the associated changes in the behavior of guided drivers) will not produce any changes in the behavior of unguided drivers; and, alternatively, that unguided drivers will apply the same behavioral rules that they used for route choice before the guidance system was in operation, but fully taking into account the responses of guided drivers to the system. Such assumptions can have a determining influence on the outcomes of modeling studies of guidance effectiveness. Turning to the behavior of guided drivers in response to information, the authors again emphasize the need to represent the variability of behavior. They highlight the differences between conventional route choice modeling and the needs of modeling driver response to guidance, including, for example, the possible occurrence of over-saturation ("information overload") when drivers are provided with large amounts of guidance. They suggest incorporating a driver's level of network knowledge (landmarks (isolated points) only; routes (a fixed sequence between landmarks); or map (including topology, distances and angles)) into models of driver response to information. They briefly discuss different path choice rules (e.g., probabilistic choice models based on random utility theory; bounded rationality and threshold models; and models that incorporate habit and decision heuristics). Finally, they also suggest that adequate modeling may require the representation of drivers' learning processes as they gain experience with the characteristics of the network, the guidance system and the traffic patterns that result.

Wolinetz, L., Khattak, A. J., and Yim, Y. (2001) "Why will Some Individuals Pay for Travel Information When It Can Be Free? Analysis of a Bay Area Traveler Survey." *Transportation Research Board 80th Annual Meeting*.

This study analyzes the preferences of automobile and transit travelers in terms of their willingness to pay (WTP) for high quality advanced traveler information services in an environment where alternative lower-quality services are free. One thousand San Francisco residents were interviewed in 1998 using CATI methods as part of the TravInfo field test. This paper reports on a simple but interesting analysis of a subset of the responses. The subset includes auto commuters, transit commuters, auto non-commuters and transit non-commuters. However, of the 1000 respondents, 342 indicated that they did not currently obtain or use traffic or transit information from any source and were not questioned further (it would have been interesting to learn why these people preferred not to use travel information.)

The remaining respondents were described a hypothetical ATIS that provides automatic notification of unexpected congestion on the usual commuting route; estimated delay time due to congestion on the usual route; automatic alternate route planning around congestion; travel time estimates on the usual route and any planned alternate routes. They were then asked stated preference questions about their willingness to pay for such a service.

The first question was whether the respondent would prefer to pay a monthly or a per-call fee for such a service. 22% replied that they would not pay and 5% were not sure, leaving 73% who indicated some willingness to pay. Of these, roughly one-quarter preferred a flat monthly rate, with the remainder preferring to pay per call.

The next questions attempted to bracket each respondent's WTP for a monthly and a per-call plan by proposing a sequence of successively lower prices and asking, in each case, if the respondent would accept the price until a positive answer is given. Surprising, the mode of the responses for both sets of questions was also the highest proposed value -- $1.00 per call (reported by 52% of those who agreed that they were willing pay something for traffic information) and $7.00 per month (reported by 39% of the "information seekers".) The paper presents a number of analyses of factors that influence the responses. The patterns appear to be sometimes different for flat fee and per call pricing.

The survey also asked stated preference questions regarding information service attributes; eight possible features were rated on an ordinal scale. The features were:

- current traffic conditions on TV or radio with updates every minute;

- detailed information about alternate routes around congestion, including directions and travel time comparisons;

- information about traffic conditions at specific locations, via telephone or computer;

- an in-car navigation system with map display of the road network indicating congestion locations and route recommendations;

- detailed information about mass transit options including schedules and station locations;

- estimate of the expected delay on the usual commute route due to congestion;

- comparison of estimated travel times to destination via alternative routes; and

- automatic notification of unexpected congestion on the usual commute route via a pager or cellular telephone.

It will be noted that four of these features were present in the hypothetical ATIS referred to in earlier questions. It was found that the respondents' valuation of these features was correlated with their willingness to pay for the hypothetical system, particularly via monthly subscription.

More generally, the most highly valued features were very frequent updates, alternate route information, an in-car navigation system, estimates of expected delay on the usual commute route, and comparisons of times on alternative routes. However, individual preferences vary considerably across these content options.

The article concludes by pointing out a few policy implications of the study. It addresses the question of whether an ATIS service could pay for itself entirely out of user fees, but does not draw a definite conclusion. However, the fact that many respondents were willing to pay some money for a futuristic system indicates that travelers value the benefits it provides. With appropriately customized content and quality, user funding may be a possibility.

It points out that more research into the demand for specific information types and combinations of types is needed; this is critical to providing services that match potential customers' needs. Also, stated preference surveys have limited effectiveness in trying to estimate WTP for services that are currently free; it would be worthwhile to start demonstration projects that charge users for travel information in order to obtain revealed preference data. In addition, more research is needed into the impacts of ATIS on aggregate travel behavior and network performance; transportation system efficiency improvements are an argument in favor of public support for ATIS. Finally, more research is needed into ATIS services for public transportation and multimodal systems.

Wunderlich, K. E., Bunch, J., and Larkin, J. "Seattle Metropolitan Model Deployment Initiative (MMDI) Evaluation." *Transportation Research Board 79th Annual Meeting*.

At the request of the Joint Program Office (JPO) for Intelligent Transportation Systems (ITS) of the Federal Highway Administration (FHWA), Mitretek Systems conducted a modeling analysis of ITS impacts in support of the Seattle, Washington Metropolitan Model Deployment Initiative (MMDI) evaluation program, called SmartTrek. SmartTrak includes a number of ATIS (various sources of traffic information) and ATMS (traffic signal coordination) measures in a freeway and arterial corridor north of the Seattle CBD.

The impact analysis focused on project features that are difficult to evaluate with direct field measurement, particularly system-wide or subarea-wide impacts. In such cases, models are helpful in systematically and independently quantifying the impacts of concurrent factors such as rising travel demand.

For the MMDI evaluation analysis, Mitretek utilized the process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN). This methodology features a conventional four-step transportation planning model as well as a traffic simulation model to capture dynamic regional and corridor-level ITS impacts. For this study, EMME/2 was the transportation planning model and INTEGRATION 1.5 was the simulation model.

ITS impacts are evaluated using the simulation model in isolation or both models in combination. The conventional planning model is employed to identify regional-level impacts on travel demand including trip distribution, mode choice and traffic assignment. The simulation model is employed to identify ITS impacts under dynamic conditions of congestion build-up and dissipation seen at the corridor level.

The simulation is applied to a series of 30 scenarios. Each scenario represents a particular combination of weather impacts, travel demand variation, as well as a pattern of incidents and accidents in the corridor. The scenarios for the evaluation were derived from a cluster analysis of traffic flow and weather and incident conditions in Seattle from the period January 1993 – January 1995. Each scenario has a weight, or probability of occurrence. The scenarios taken together comprise a representative year of operation.

The network was calibrated with an analysis of traffic flow counts against observed data and a calibration of within-peak travel time variation and day-to-day reliability of freeway travel, but separate surveys to estimate a driver behavior model were not carried out.

The calibrated network without any MMDI-related enhancements served as the baseline case in the experimental plan. This baseline case represents the state of infrastructure and utilization of traveler information services prior to the MMDI evaluation time frame. The baseline case is not a "no-ITS" case: it includes long standing traveler information services and traffic control technologies.

Four potential improvements relative to the baseline case were evaluated via experiments using the model system. An ATMS experiment evaluated the impact of coordinated control along SR99 and SR522. An ATIS experiment was conducted to examine impacts of the current freeway-only ATIS at current levels of traveler usage. A cross-functional ATIS/ATMS deployment was evaluated in the enhanced ITS analyses. These enhanced analyses examine concurrent improvements to traffic signal control as well as provision of more comprehensive ATIS services.

Improved fixed-time signal coordination along SR99 and SR522 results in 7% delay reduction and reduction in vehicle-stops at the subarea level without negative impact on cross-street traffic. Although coordinated, optimized fixed timing plans are beneficial, the range of conditions seen in the corridor cannot always be satisfied with a single fixed plan. Integrating arterial congestion data with freeway-based ATIS clearly improves the effective utilization of ATIS services. The delay reduction associated with a 6% usage rate in the AM peak more than doubles from 1.5% to 3.4% when congestion data on parallel arterial facilities is made available to ATIS. Delay reduction from ATIS provision and ATIS enhancement to include arterial streets is concentrated among travelers making trips in the corridor of 18-25 km in length. Including local arterials in freeway-based ATIS results in reduced freeway-to-arterial diversion. Interactions from the concurrent deployment of fixed time signal coordination and enhanced freeway/arterial ATIS are limited.

Wunderlich, K. E., M. H. Hardy, J. J. Larkin and V. P. Shah (2001). *On-Time Reliability Impacts of Advanced Traveler Information Services (ATIS): Washington, DC Case Study*, Mitretek Systems.

Shah, V., A. Toppen, M. Vasudevan, K. Wunderlich, S. Jung and J. Larkin (2001). *On-Time Reliability Impacts of Advanced Traveler Information Services (ATIS), Volume II: Extensions and Applications of the Simulated Yoked Study Concept* - Draft Final Report, Mitretek Systems.

Shah, V. P., Wunderlich, K. E., and Larkin, J. "Time Management Impacts of Pre-Trip ATIS: Findings from a Washington DC Case Study." *Transportation Research Board 80th Annual Meeting*.

The first two documents are reports of a research study carried out by Mitretek Systems on the impacts of ATIS on travel time and travel time reliability. The third document is an article that summarizes key findings from the study.

The authors conducted a simulated yoked study (paired driver study) drawing on archives of observed road congestion in the Washington, DC area road network. The study compared the individual driving and arrival times of simulated network travelers with and without access to pre-trip ATIS information, based on large numbers of simulated trips over the network and over time. The simulated yoked approach is called HOWLATE (Heuristic On-Line Web-Linked Arrival Time Estimator).

The basis for the method is an archive of estimated link times that was compiled by automatically polling a traffic information service (SmarTraveler) every five minutes and recording the reported prevailing times. This archive allows a reconstruction of the travel time that would have been experienced by a trip made at a particular time and on a particular path.

In the HOWLATE method, path and departure time choices are simulated for two identical travelers, one of whom does not have access to pre-trip ATIS while the other does. Both travelers are assumed to start from the same origin and to want to arrive at the same destination at the same time. However, each is free to choose the departure time and travel path. The travel times and on-time arrival record for each traveler are then reconstructed from the archived link times. Performance statistics are maintained and output at the end of a determined number of simulated trips.

Drivers who do not use ATIS are assumed to build up over time a personal estimate of the travel times on different links during the commute period. They choose the path that appears fastest based on the estimated times, and determine when to depart based on their desired arrival time and expected travel time, but also add some slack to account for possible variations in actual times. This experience establishes a habitual departure time and path choice behavior for the non-users, who are assumed to always make these choices. Drivers who do use ATIS are assumed to rely on the link time information provided in “real-time” (i.e., just before their simulated trip) to determine their path and departure time choice, again given a desired arrival time at the destination.

Consequences of the departure time and path choices are then evaluated using the link time archives. Link time values from the archive are perturbed by the addition of a random term that reflects the statistical accuracy of the archived times compared against actual travel times measured in field trials. Using these perturbed values, the HOWLATE method calculates the path time and arrival time that each user would have experienced, based on the departure time and path choices.

The broad conclusion from the study is that pre-trip ATIS has a relatively small impact or even negligible impact on the average travel times experienced by its users. However, pre-trip ATIS users can significantly reduce their early and late schedule delay as well as reduce the number of late arrivals compared to their counterparts who are non-users of ATIS. In other words, the principal impact of the ATIS information was to reduce the unpredictability of travel times and to allow a more efficient scheduling of trips to reduce both early and late schedule delays.

Some of the main specific findings from the study are:

- non-users are three to six times as likely to arrive late compared to pre-trip ATIS users;
- cases where pre-trip ATIS clearly benefits the user outweighed cases where pre-trip ATIS clearly disadvantages the user by five to one;
- the number of late arrivals is reduced by 62.5% and the total late schedule delay is reduced by 72% through pre-trip ATIS use;
- late shock, the surprise of arriving late, is reduced by 81% through ATIS use;
- user perception of pre-trip ATIS impact is approximately 98% accurate.

The results also showed that the benefits of pre-trip ATIS use vary significantly by time of day and by specific trips. During the morning peak, the number of late arrivals and the total schedule delay reduced by 45% and 51% respectively for pre-trip ATIS users. Total early schedule delay reduced by 28%.

Follow-on work, described in Volume II of the study report, extended the initial application of HOWLATE to two larger case studies in the Washington, DC and Minneapolis/St. Paul areas.

Furthermore, the study evaluated the travel time savings and reliability improvements using methods and values presented by (Small, Noland et al. 1999), and attempted to distinguish the nature and magnitude of ATIS impacts on familiar and unfamiliar drivers.

Results for the larger Washington study broadly replicated those found in the original (Volume I) study, and those for the Twin Cities broadly matched those found for Washington. An interesting difference was that Twin Cities ATIS users could sometimes make worse choices than non-users in off-peak periods because traffic there exhibits less actual variability than the randomly perturbed archived travel times. As might be expected from its higher level of inherent congestion, the absolute and relative benefits of pre-trip ATIS were higher in the Washington DC area. However, the benefits of pre-trip ATIS were found to be concentrated both geographically and by time of day. Furthermore, departure time changes were typically the optimal response to ATIS information much (six to twenty times) more frequently than path choice changes.

The follow-on work also investigated the impacts of en route ATIS on travel time and time unreliability reduction. It was found that benefits in these areas only occurred in relatively specific situations: long trips encountering unexpected congestion and having viable diversion opportunities throughout their trip. The results (which are preliminary) appear to imply that the value of en route diversion decreases following changes following any changes that may be made at the start of the trip.

Yim, Y., and Ygnace, J.-L. (1996). "Link Flow Evaluation Using Loop Detector Data: Traveler Response to Variable Messages Signs." *Transportation Research Record*, 1550, 58-64.

The objective of this study is to assess the effects of VMS on individual link flow. This paper is concerned with the extent to which roadside traffic information influences route choice so that existing freeways can be more efficiently used. The broad research issues were whether the link flow rates with VMS under SIRIUS (an expert system called *Système d'Information Routière Intelligible aux Usagers* in Paris) are significantly different from the flow rates without VMS, and to what extent VMS affects motorists' route choices. More specifically, the questions whether 1) there is a significant change in link flow after the message change, 2) there is a variation in link flow under different messages because motorists respond differently to different types of messages, and 3) traffic stream flow data on a single link should be used for evaluation of driver response to VMS. This paper reports the results of the traffic flow data analysis addressing these issues for a selected link.

To understand the user requirements of VMS, the French National Department of Transportation (DoT) conducted traveler surveys in the Paris region. In May 1992, a mail survey was distributed among Paris area motorists with a sample size of 8000. A follow-up telephone survey was conducted shortly thereafter with 100 participants. These surveys focused primarily on gathering information about the cognitive ability of motorists to comprehend and interpret roadside messages. Based on the findings of the motorist surveys, VMS were designed and installed at locations that allowed drivers to make diversion decisions before reaching a congested section of a freeway.

Based on the traveler survey results, the French DoT estimated that 50 percent of vehicles would divert given the choice between congested and free flowing links. Given the choice between two congested links, 3 to 5 percent of motorists would divert to the less congested link when comparative information were provided on these links. To verify the stated diversion behavior, it was decided to measure the revealed changes in link flow using loop detector data. One of the technical challenges of the SIRIUS evaluation study was to estimate the actual number of vehicles diverted using the minimal amount of traffic data available. In this paper, several methods are explored that can be used to measure the shift of link flow using loop detector data on a single link after the SIRIUS system is implemented.

The effects of VMS on link flow were investigated, using loop detector data on the access ramp to a freeway from its parallel arterial road. Link flow data were analyzed mainly using t-test statistical techniques and arrival curve graphical methods. Despite some methodological limitations that were encountered in obtaining counts of vehicles actually diverted by traffic information, the methods used in this study were found to be useful, especially in obtaining qualitative assessments of traffic behavior for a given link. The study also found that the revealed diversion behavior was more conservative than the stated preference of those drivers who responded to the 1992 surveys in the Paris region.

The key findings of the study are that 1) there is evidence indicating VMS alone can significantly affect vehicle diversion; 2) VMS are most effective when the information is disseminated during periods of increasing congestion; 3) driver response to VMS during morning peak hours is more significant than during evening peak hours; 4) there is a close relationship between diversion behavior and queue length information – the longer the queue, the greater the number of vehicles that diverted; and 5) it is possible to measure the effects of VMS on diversion behavior using loop detector data from a single link without the historical data. The comparative analysis between the link flow data using the continuous dissemination of traffic information and the flow data using intermittent displays of information showed little difference in link flow behavior on the access ramp to the freeway.

According to the data analysis using the continuous dissemination of queue information on the freeway, the flow rate was closely associated with traffic information regarding congestion level. The statistical analysis showed that a queue length of 3 km appears to be a threshold at which a significant number of drivers responded to the VMS. The graphical analysis showed that with a message indicating a 4 km queue, the traffic flow on the access ramp reduced to 30 percent below capacity. With a message indicating a 3 km queue, flow was reduced to 15 percent below capacity. Flow was reduced to 10 percent below capacity with a message indicating a 2 km queue. Flow was reduced to 7 percent below capacity with a message indicating a 1 km queue. The VMS had almost no effect on the flow rate when the message indicated a 0.5 km queue.

Yim, Y., and Miller, M. A. (2000). "Evaluation of the TravInfo Field Operational Test.", California PATH Program, Institute of Transportation Studies, University of California, Berkeley.

Travinfo^{TM} is a regional traveler information system in the San Francisco Bay Area. It was a Field Operational Test (FOT) over a two-year period from September 1996 to September 1998 with funding from the Federal Highway Administration and the California Department of Transportation (Caltrans). Travinfo^{TM}'s goal was to broadly disseminate accurate, comprehensive, timely and reliable information on traffic conditions and multi-modal travel options to the public in the Bay Area.

The California PATH Program at the University of California, Berkeley conducted an evaluation of the field test. The evaluation focused on three areas: institutional, technology and traveler response. It was performed using a variety of data sources including field observations, focus group discussions, traveler surveys, and field measurements. An Evaluation Oversight Team was formed from representatives of public agencies, practitioners, and the academic community to provide advice to the evaluators, and to serve as a communications link between the evaluators and the project partners.

Institutional Evaluation

Travinfo^{TM}'s organizational structure was unique because of the high degree of openness in the public-private partnership. Travinfo^{TM} meetings were conducted as open forums to encourage the entrepreneurial participation of members of the traveler information industry as well as active participation of local public agencies. The evaluation concluded that the Travinfo^{TM} organization was effective in appropriately utilizing public and private sector talent. It found that the most significant attribute of the Travinfo^{TM} field test was the creation of partnerships among public and private parties. The project helped foster constructive relationships among the three principal public agencies, and the benefits carried over into other joint ventures.

Technology Evaluation

Two sources of data were fed automatically into the Travinfo^{TM} database: data from the inductive loop sensors of Caltrans' Traffic Operations Systems and data from the freeway service patrol. However, these sources did not provide sufficient geographic data coverage or accuracy. As a result, the most significant source of data soon became incident reports of the Computer-Aided Dispatch system from the California Highway Patrol. Because of the manual nature of the Travinfo^{TM} system, the operator's response time is critical to how well the center meets its goal of timely, comprehensive, and reliable dissemination of traveler information. During the field test, it took an average of 10 to 11 minutes to process an incident from the

Highway Patrol's Computer-Aided Dispatch System and enter it into the Traveler Advisory Telephone System. Approximately 20% of the total number of incoming Computer-Aided Dispatch incidents were entered. Operator's job performance and their workloads were the two primary factors influencing the number of incidents they entered into the system and the time required to do so.

The physical environment of the Traveler Information Center proved to be acceptable, and operator performance was not directly related to working conditions. Overall, competent staff was employed at the center, and management oversight measures were taken to monitor performance. Relying on operators to perform Travinfo™ tasks proved time-consuming, especially in the transfer of incident data from the Computer-Aided Dispatch system's terminal to the center's system, and from the center's system to the telephone advisory system. It was concluded that automating the data entry process would speed operators' response times and increase the number of incidents they could process.

By the end of the field test, over 50 information service providers registered with Travinfo™. Of that group, 90% were in the private sector. The Travinfo™ field test was effective in eliciting participation from information service providers and resolving issues concerning the public sector's potential competition with the private sector.

Traveler Response Evaluation

Commercial radio reports were the primary source of traffic and transit information in the Bay Area. One-third of Bay Area households listened to radio traffic reports on a regular basis, and an additional one-third listened occasionally when a traffic problem was expected. According to a household survey conducted in 1998, the impact of radio and television reports on the entire traveling population including non-listeners is approximately 12%. People modified their travel behavior, mostly by leaving earlier and taking alternate routes. Very few people chose public transit.

The surveys also showed that the vast majority of Bay Area households were not aware of the Travinfo™ Traveler Advisory Telephone Service or traffic websites. Of the 9% of Bay Area households that were aware of Travinfo™, very few had actually tried it. Among those who did use the Travinfo™ telephone service or websites, their satisfaction level was consistently high; they rated the quality of information to be far superior to radio or television reports and perceived it to be useful in their trip planning.

Initially, less than 1% of the Travinfo™ callers asked to be rerouted to the transit menu after learning about bad traffic conditions from the traffic menu. However, the second survey, conducted after the field test, showed that 5% of the callers were rerouted to the transit menu, a significant increase, and 90% of them switched to transit. Travinfo™ was able to capture those who never listened to radio or television reports; it also led people to substitute Travinfo™ telephone advice or websites for radio or television reports and to seek out more information.

Although Travinfo™'s short-term effect on the overall transportation system appears to have been marginal, Travinfo™ was able to influence travel behavior far more effectively than radio or television traffic broadcasts. 25% of those who obtained relevant information from radio or television changed their travel behavior, while nearly twice as many of the Travinfo™ callers, 45%, and more than three times as many of the web site visitors, 81%, reported altering their trips after obtaining information specifically about their routes.

Lessons Learned

From the institutional point of view, it was necessary to adjust the public and private partners' differing expectations for Travinfo™ in order to work toward the common goal of disseminating information to Bay Area travelers. The public partners expected to make Travinfo™ available for better congestion management, while the private partners expected to test and market products that would make a profit. It took a long time to reconcile their differing objectives. In addition, the field test's goals were too ambitious and unrealistic to achieve within the allotted time.

The Travinfo™ system is not as efficient as originally envisioned because of its heavier-than-expected dependence on the manual performance of jobs by the Traveler Information Center Operators. Travinfo™ needs an automated system that is flexible enough to keep up with rapidly advancing technologies, which will likely require its system components to be enhanced and upgraded.

Perhaps the greatest value of the Travinfo™ field test comes from sharing the experiences from it with others. Since it was the first to test the concepts of open architecture and open partnership, it has a wealth of findings. The partners gained knowledge of building successful partnerships through, among other things, better understanding of different points of view and objectives, and improved communication.

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