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Public Acceptance and User Response to ATIS Products and Services: The Use of Travel Simulators to Investigate the Response to Traffic Information

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FOREWORD

The following is one of a series of papers developed or produced by the Economic Analysis Division of the John A. Volpe National Transportation Systems Center as part of its research project looking into issues surrounding user response and market development for selected Intelligent Vehicle-Highway Systems (IVHS) products or services. The project, sponsored by the Federal Highway Administration's Office of Policy Development, was one part of FHWA's 1992 Institutional Issues Program entitled -- "Public Acceptance and Markets for Various Consumer IVHS Services". John O'Donnell of the Volpe Center and James March of FHWA served as Project Managers for their organizations.

The objective of the Volpe Center project was to better understand factors affecting the development and deployment of selected advanced traveler information products and services (ATIS). The Center addressed the objective by examining the development of markets for selected ATIS-related products and services and reviewing factors affecting the public acceptance and user response to existing traffic information services.

Deployment of many of the newly emerging and projected IVHS products and services will depend upon consumers purchasing and otherwise choosing to make use of advanced traffic and travel information products and services. Through four different projects, each with a distinctive approach to understanding consumer response and market demand, the Volpe Center explored the question: Given the opportunity to buy a product or subscribe to a service that promises to deliver traveler information, will the consumer perceive that there is sufficient benefit to be gained to justify the investment?

The Volpe Center and FHWA jointly conducted a workshop in the Fall of 1992 to discuss issues involved with assessing the market for IVHS products and services. The objectives of the workshop were to help define a research program which would address measuring user acceptance and response to ATIS products and services and the role market research plays in understanding emerging markets for new or unknown products and services.

The results of the workshop are reflected in the four research tasks initiated as part of this program and the seven papers which comprise it. The four task areas are summarized below. Copies of the papers will be provided upon request to the Volpe Center.

TASK 1. Industry Methods for Assessing Consumer Response to New Products/Services

The first project was designed to answer the question of how consumer response and market demand are measured in the commercial sector, where these market demand questions are fundamental to the survival and success of the business. This project has two parts. The first is a primer on how consumer marketing research is done in the commercial sector. The second presents three case studies that examine how three current high-technology communications and travel products applied marketing research in preparation for market release.

Report 1A. *A Primer on Consumer Marketing Research: Procedures, Methods, and Tools*

The Volpe Center developed a marketing research primer which provides a guide to the approach, procedures, and research tools used by private industry in predicting consumer response. The final two chapters of the primer focus on the challenges of doing marketing research on "revolutionary" products, or those products which the consumer has had no direct experience with, as is the case with most IVHS products and services. This primer was designed to provide the non-marketing researcher with a good understanding of how this particular type of human behavior research is pursued.

Report 1B. *Case Studies of Market Research for Three Transportation Communications Products: Electronic Toll Collection, Advanced Vehicle Information and Location, and Cellular Telephones*

Three case studies were undertaken to demonstrate the application of marketing research to products which are analogous to ATIS products and services, to learn from the market experience of these three ATIS-analogous products any lessons which might be applicable to future ATIS research, and also to demonstrate the uncertainty - despite good research design and assumptions - of marketing research predictions. The case studies were written by Thomas Parish of Arthur D. Little, Inc.

TASK 2. *ATIS Market Research: A Survey of Operational Tests and University Research*

The challenge of marketing research is much more difficult where the consumer has not had direct personal experience using the proposed product in daily life. The operational tests provide an excellent opportunity for gathering consumer response and market demand information from "experienced" consumers. The Volpe Center team surveyed the operational tests that were extant or complete (as of 8/93) to learn whether any consumer response/market demand information had been collected and analyzed. The survey was extended to include government-sponsored university research projects so as to provide a more complete overview of the current national research program in relation to this question.

TASK 3. *A Market Analysis of the Commercial Traffic Information Business*

What kind of traffic information is available to consumers right now? How do consumers respond to current offerings? What are the market/economic fundamentals that underlie this market?

The traffic information services business is well-established and a study of its market fundamentals yields insight into consumer response to ATIS as well as providing useful information to policy makers who are considering the future role of government in this arena. This report describes how traffic information is gathered, processed, packaged, wholesaled, and retailed on the variety of platforms which are available on the market today.

TASK 4. Laboratory Simulation of ATIS for Testing Drivers' Response

This project was formulated to explore the feasibility of enhancing existing laboratory or PC-based driver decision simulators which have the ability to gather revealed preference data and test drivers' decisions in the presence of traffic information. Such simulators, it was hypothesized, could supplement operational tests as a source of consumer response and market demand data. The work was performed at MIT under the leadership of Professor Moshe Ben-Akiva.

Report 4A. *State of the Art of ATIS Driver Simulators*

The project was divided into three parts. The first, covered in this report, reviewed all existing driver simulators to learn whether any were sufficiently sophisticated to be used, as is, to reliably test drivers' response to traffic information.

Report 4B. *A Review of ATIS Operational Tests*

The design of any laboratory-based simulator is based upon a model of how individuals respond to stimulus, in this case ATIS products. To construct a model, one must first study the natural behavior of live subjects in an actual ATIS driving situation. Report 4B looks to the existing and completed ATIS operational tests to learn whether data has been produced that is suitable for the purposes of developing or improving ATIS models.

Report 4C. *A Modeling Framework for User Response to ATIS*

This report focuses on the information required to support the development of a modeling framework for driver response to ATIS. In it, the author identifies the stages of user response to ATIS, outlines the key factors associated with each decision, and discusses the data which would be required to complete the model, and thus construct a reliable, durable driver simulator.

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Chapter 1

Introduction

1.1 Motivation

Increasing attention has been paid in recent years to the use of Advanced Traveler Information Systems (ATIS) for alleviating traffic congestion. Understanding user response to traffic, transit and parking information, is important both for designing ATIS operations and for evaluating their effectiveness and resulting benefits. Such understanding is usually based on developing models that capture user behavior in the presence of information. However, data that can assist the model development effort is not readily available.

In general revealed preference (RP) and stated preference (SP) data are the two basic approaches of data collection for modeling user behavior. Revealed preferences indicate how travelers behave in real-life situations, for example observation of travelers' actual diversion behavior in response to information acquisition. Stated preference data indicate how travelers behave in hypothetical scenarios. Stated preference data can be extracted by SP surveys or by simulation experiments.

Currently, uncoordinated preliminary research projects at a number of universities have resulted in the development of ATIS travel simulators useful to collect SP data. This report makes a distinction between travel simulators, used to study the travelers response to information acquisition, and driving simulators which are elaborate tools used mainly for human factors research. Travel simulators are only in the initial development stage and require further development and testing. The advantage of travel simulators is that mass SP data can be easily collected in a controlled environment. Moreover, it is a relatively inexpensive data collection methodology that allows the testing of the effect of a variety of existent and non-existent ATIS on travelers behavior. However, because this data indicate how travelers behave in hypothetical scenarios, the validity of the responses is a critical concern. For example, subjects may not be able to perceive the differences in alternate trip scenarios (such as recreational vs. work trips). Also, differences in the laboratory settings might cause significant changes in the results. On the other hand, revealed preference data, although much more expensive and difficult to collect, does not suffer from the above drawbacks.

In order to assure the validity of the models developed and the conclusions drawn by simulation experiments, it is important that field experiment data be used. For example, the use of the same subjects in both field studies and simulation experiments can provide the means to identify biases introduced by travel simulators.

Ongoing demonstration projects may provide valuable data that can be used to enhance data collected by travel simulators. However, these tests and data collection activities must be designed with a view toward the development of general model formulation and testing concepts that can be widely applied to evaluate existing or future ATIS. Thus there is a need for a concentrated effort to design and coordinate a comprehensive program to collect data using different approaches and to design alternative modeling approaches that would be supported by these data.

1.2 Objectives

The purpose of this research is to develop a comprehensive and coordinated approach to collect data (both from demonstration projects and traveler simulators) and develop models of the user response to ATIS products and services. The models developed will provide a key input to a meaningful analysis of the travelers' behavior in the presence of traffic information provided by ATIS systems.

The research is designed to address questions such as:

- who will use the ATIS products and services?
- how often?
- for what purpose?
- in which areas?
- how will use of these products and services affect the users' travel?

The purpose of the research is to identify:

- factors that affect the acquisition and usage of these ATIS products and services;
- learning behavior of potential users; and
- ways in which different ATIS products and services affect travel behavior.

The key issues that will be addressed in the initial phase of the research are:

- how can data from travel simulators be used for modeling user behavior in the presence of information;
- methods to enhance data collected from travel simulators; and
- methods to augment these data with data from established or proposed ATIS operational tests.

1.3 ATIS User Response Framework

A potential framework for the overall research program on users response would include three major elements:

1. **ATIS Accessibility:** The willingness of travelers to acquire equipment or subscribe to services that permit access to ATIS. Associated research should focus on factors influencing market acceptance, including willingness to pay.

2. **ATIS Usage:** The frequency that ATIS products and services will be used by travelers. Factors affecting utilization include the quality and perceived value of the ATIS services provided, traffic weather conditions, familiarity with the network and other traveler and trip characteristics.

3. **Travel Response:** The behavioral responses of ATIS users and the extent to which ATIS affect travel behavior. An example would be the rate of acceptance of route guidance recommendations.

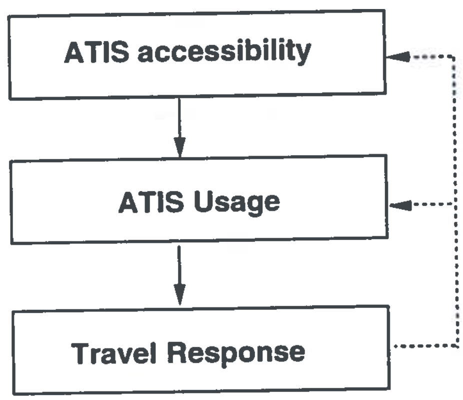

Figure 1.1: Framework for IVHS End-User Response Analysis

The relationships among the above three elements of user response analysis are shown in Figure 1. Solid arrows represent the sequential nature of acquisition, usage and response decisions; dotted arrows represent feedback effects, or learning behaviors, that occur over time as users gain information about the nature and reliability of different ATIS.

1.3.1 Overall Methodology

The methodology for user behavior research of this nature consists of two components:

- Data collection
- Data analysis and modeling

1. Data collection

   Data on user behavior should be collected using a combination of approaches. Direct observations of user acceptance and reactions to ATIS could be obtained from:

   - simulated laboratory experiments; and
   - field operational tests.

2. Data analysis and modeling

   Methods for the analysis of the collected data range from simple explanatory data analyses to obtaining descriptive statistics and analyzing individual behavior using advanced statistical methods.

This report (Volume II) presents a review of existing travel simulators and ongoing data collection and modeling efforts using these simulators. The report also suggests approaches for evaluating the validity of data collected through travel simulators in general.

1.4 Report Outline

The report consists of 5 chapters.

Chapter 2 provides general background information on simulators, highlights the advantages and disadvantages of using simulators to investigate travelers' behavior, and establishes the basis of evaluation of existing travel simulators.

Chapter 3 reviews the most recent literature on travel simulators and discusses major findings on data collected by the simulators and associated model development.

Chapter 4 presents the advantages and disadvantages of the developed simulators and gives an overall assessment of travel simulators.

Chapter 5 provides some suggestions for further research.

Chapter 2

Travel Simulators

2.1 Definition of Simulators

In simulators a specific system or equipment is represented through either artificial duplication of equipment or embedding artificial input and measurement features in actual equipment. The system is interactive in that human input results in changes to the equipment, which evokes an operator response (Jones *et al*, 1985).

2.1.1 Applications of Simulators

Traditionally simulators have been used for training purposes such as flight and army simulators (Jones *et al*, 1985). In these cases the simulator is an interactive device to facilitate familiarization, acquisition of skills, learning of tasks and practicing segments of or complete missions. These simulators duplicate all or part of the actual equipment or systems and can be used for individual training as well as for crew, team, or entire unit training (such as aircraft pilots, astronauts, nuclear submarine pilots, nuclear power plant operators, etc.)

More recently simulators have been used for the design, development, and evaluation of standards, procedures and systems (such as manual control transfer functions, sensory-motor information processing, telerobotics and virtual reality), as well as for conducting applied market research (consumer reaction and product evaluation).

Hauser *et al* (1992) employed a market information simulator to examine consumer behavior when evaluating a brand for inclusion in their consideration set. The purpose of their study was to investigate the value of information, the order in which people acquire information from different sources, and how this information affects choice. A multi-media computer laboratory allowed "shoppers" for a new automobile to choose among showroom visits, word-of-mouth interviews, magazine articles and advertising in order to collect the necessary information. This new methodology for developing preproduction forecasts for durable goods is based on the concept of "information acceleration"(see Weinberg (1993) for details). Information acceleration facilitates: 1) simulating the existence of a future new durable good, 2) simulating the availability of new durable good information that is typically available not only before but also after market launch, 3) simulating the availability of competition, 4) enabling consumer information search and interaction with the new durable good and competitive products, and 5) recording critical behavior with regard to consumer information search and consideration for the new durable good. The new methodology was validated with respect to measures used for pre-market forecasting. The results suggested that the computer-based video retail outlet appears to be a potential surrogate for real retail outlet with respect to measures used not only for developing market forecasts (e.g. purchase intent), but also for understanding consumer search behavior (e.g. amount of time allocated to a search activity).

For the purposes of this report we divide simulators that have been developed for traffic applications in travel simulators and driving simulators. Travel simulators are mostly PC-based applications used to study the subjects travel decisions (such as departure time choice and route choice) when traffic information is provided to them, and to collect reliable data for modeling travelers behavior. On the other hand, driving simulators are expensive and elaborate tools which use a combination of seat, steering wheel and foot control, used mainly to provide a realistic driving environment for human factors research.

Travel simulators are designed with emphasis on collecting reliable data on motorists responses to information, while driving simulators' design emphasizes on data collection related to vehicle design, roadway visualization, product testing and computer market research. Due to their importance and potential of use of driving simulators in collecting travelers behavior data (Kantowitz, 1993) , a brief literature review of the existing driving simulators and their current use is presented in Appendix A.

2.1.2 Assessing the Value of a Simulator

Simulators are becoming more realistic, accurate, and comprehensive representations of a particular item of equipment or a system through technological advances. An important concern in the design and use of simulators is the ability to elicit valid behavior. In general, *validity* of a simulator refers to the correspondence between the results acquired by using the simulator and a set of outcomes that are needed or desired and constitute the objectives of its use. In our case, this relates to the travelers' behavior under ATIS in the simulation and their actual behavior in real situations. The validity of a simulator is a function of its fidelity. *Fidelity* refers to the accuracy of the correspondence between the simulator and the operating environment (in our case, the travel and informational environment). Specifically, two elements of fidelity of the simulator can be distinguished: realism (accuracy in physical representation) and comprehensiveness (degree of completeness of representation of all functions, environmental characteristics, etc.)

To evaluate the validity of a simulator it is necessary to consider the purposes for its use and formulate objectives for that use. Formulation of meaningful outcome specifications involving behavioral and cognitive factors requires analysis of the psychological requirements of tasks to be performed in the simulation situation, as well as in the simulated operational environment. One very important step for a behavioral scientist is to decide which studies to perform in which environment. Furthermore, an important factor affecting the development and degree of sophistication of a simulator is the tradeoff between cost and fidelity.

In our study we will focus on travel simulators which are used to investigate travelers' behavior in response to ATIS. As Polak *et al* (1992) note there are three distinct categories of research related to the use of ATIS simulators:

1. **In-vehicle behavior** research related to the drivers' behavior in response to vehicle and in-vehicle systems design;

2. **Driving behavior** research related to the drivers behavior in relation to the driving task such as car following behavior, overtaking, gap acceptance, manoeuvring and signal behavior; and

3. **Travel behavior** research related to the travelers choices such as mode choice, route choice, diversion decisions, compliance with ATIS advises, etc. with respect to information provided by a variety of information sources such as route guidance systems, variable message signs, maps, etc.

Although it is very difficult to draw the boundaries between these three research areas, our review and analysis will involve only the third category of research which is conducted usually with travel simulators. Note that most travel simulators that examine the travelers' behavior under ATIS are used for data collection purposes and are low-cost simulators mainly developed in Universities (see Chapter 3). On the other hand, driving simulators are currently used for research in the first two categories It is still not clear if the high levels of sophistication and fidelity provided by the existing driving simulators are needed in the study of travelers behavior when information about traffic conditions, accident delays and route guidance is provided. Further research on the effect of the simulator design on traveler's decision making should be conducted. However, the results and suggestions of this research are directly applicable to all simulators used for travel behavior research.

The following section contains a discussion about the relevant advantages and disadvantages of data collected from simulators. Furthermore, we will set the standards upon which the travel simulators reviewed in the next chapter will be evaluated.

2.2 Data Collection - Advantages and Disadvantages of Using Simulators

The data obtained from simulators is Stated Preferences (SP) data and indicates how travelers behave in hypothetical scenarios.

Stated preferences can capture some aspects of latent preferences and therefore could help in the identification and estimation of the latent preferences that determine actual behavior. For example, the use of an advanced travel simulator with a complicated map display could present an opportunity to examine the spatial behavior of the travelers and the actual learning of the network, through the knowledge acquired from experience and information provision. Moreover the attributes of the alternatives are free of measurement errors although subject to perception errors. Intangible attributes such as reliability and relevance of information provision can be incorporated. SP data can also elicit preferences for new alternatives, such as introduction of a new information system. The most important advantages of simulators is the ability to control and to repeat multiple times the experiments conducted.

In general the validity of the responses acquired through SP surveys are a critical concern (Morikawa, 1989) due to the various biases that may be introduced. Simulators present "artificial realities" and subjects are aware of this fact. Biases in the SP data can be introduced by the indifference of the respondents to the experimental task, by the imperfect description of the alternatives and by omission of situational constraints. Examples revealing the above biases are the following:

- **Prominence Hypothesis Bias** can be observed in the cases of subjects who always decide to follow the route with minimum travel time and therefore switch from their preselected route without having any rational boundaries on their switching behavior. Another example is subjects who consistently decide to follow the advice provided by the ATIS without any concern for the quality of the information provided.

- **Policy-Response Bias** can be observed in cases where the subjects believe they will benefit by a certain response; for example, when they are asked about a probable purchase of a route-guidance system or about the usefulness of various ATIS features.

- **Preference Inertia** can be observed in the cases of subjects who continue to follow their first chosen route. This initial choice satisfied their criteria, and thus they never choose an alternative route.

- **Justification Bias** can be caused by respondents attempts to justify previous choices. For example, a respondent may choose to ignore traffic information in order to demonstrate that a route previously chosen according to personal judgment is superior to the ATIS recommendations.

- **Content Effects** can arise when the developed simulator does not realistically represent the attributes of alternative situations. Experience with the use of travel simulators (for example, see Polak, 1992) has shown that it is difficult for the subjects to perceive the differences among travel scenarios, such as different trip purposes or weather conditions. However, in real life, commuters very familiar with a road network know from experience that a rainy day alters its performance. Moreover, trip purpose might strongly affect travelers' decisions; one might prefer to drive on a scenic route on the way to a recreation activity.

- **Omission of Situational Constraints** is another context effect which arises when a subject ignores situational constraints that would influence choice behavior in real-world situations.

- **Effects of Incentives** may be caused by the desire to overcome some of the above biases. For instance, to make the simulation more realistic, subjects are usually given certain incentives to participate and certain goals to achieve. However, differences in laboratory settings might cause significant changes in results. For example, it has been noticed that when the experiment offers a prize for the first traveler to arrive at his destination, subjects tend to switch more frequently than they would otherwise. Conversely, when there is a penalty delay people tend to switch less and be more risk adverse (see Van der Mede, 1991). Therefore the set-up of the experiment might significantly change its outcome.

Finally, looking from a human factors perspective, travel simulators might stimulate differently alternate categories of subjects, for example subjects that are familiar with computers vs. unfamiliar subjects, younger vs. older subjects, men vs.woman etc. (Hein, 1993)

2.3 Evaluation Criteria

In this study we focus on travel simulators developed to investigate travelers decisions in response ATIS and we will establish criteria for their evaluation. As was mentioned in the introductory discussion about simulators the fidelity of a simulator affects its validity, i.e. how close the behavior observed in the simulator is to actual traveler behavior under the provision of information. However, the extent to which the sophistication of a simulator affects its validity is not known. As will be demonstrated later on further research, this information is required to establish this relationship in the case of travel simulators. The fidelity of an ATIS travel simulator is a function of the following elements:

1. **Network Representation**

   The flexibility of the network representation (fixed or variable) is very important, since both hypothetical and real networks can be used to investigate differences in traveler's behavior. The generation of traffic conditions, travel times, incidents etc., affects the simulators fidelity and hence subjects' decisions.

   The complexity of the network representation plays an important role in the subjects' choices. Factors such as number of alternative routes, number of lanes on each route and number of traffic lights and stops are expected to have significant effects on subject's behavior.

2. **Travel And Driving Task**

   The simulation of the travel tasks plays an important role. The more sophisticated the travel environment is, the more reliable the results will be (although a high degree of sophistication does not necessarily guarantees good results). The simplest and most common travel simulators resemble PC games where "travelers" use the keyboard to move the vehicle (represented by a cursor) on the screen. In more elaborate configurations, subjects sit in front of a steering wheel and foot controls. Although the first simulator type seems too simplistic for simulating travelers' behavior, some extra characteristics can be added to make the travel task more reliable.

   Most of the simulator experiments give the volunteers certain incentives to participate and travel purposes to make the experiment more attractive and the travel task more realistic. However, it has been noticed that the participants' behavior varies according to these incentives or purposes, and therefore the validity of the experimental results is questionable. However, these context-specific experiments could be more elaborate in order to present the subjects with alternative travel scenarios that are relevant to their needs and their characteristics.

3. **Information provision**

   The provision of information is another important factor affecting travelers' decisions. The visibility and comprehensiveness of signs, maps and route guidance are factors affecting subjects' information acquisition and relevant attitudes. Redundant or overloading information should be eliminated in order to avoid subjects' fatigue. It is expected that different types of information provided will result in different travelers' decisions. Information characteristics such as credibility, timing, location of the message provided are expected to be important.

Finally, it should be noted that the choices of the travelers also depend on socioeconomic factors such as age, gender, and income, as well as personality, habits, travel experience and familiarity with the transportation network. Therefore, the results of experiments conducted with convenient samples, such as college students, do not necessarily represent the whole population.

Chapter 3

Review of Travel Simulators

This chapter reviews travel simulators developed in different institutions to address the impact of ATIS on travelers' behavior. The review includes simulators developed at the following institutions:

- Kyoto University, Japan
- Massachusetts Institute of Technology
- Systems Technology, INC and JFT Associates, CA
- TNO Institute for Human Factors
- University of California at Davis
- University of California at Irvine
- University of Leeds, England
- University of Texas at Austin

In order to obtain more up-to-date information about existing simulators, a questionnaire was developed (see Appendices B and C) and sent to the above universities and organizations. The following is based on published papers and questionnaire responses. Also, other efforts for which full information is not available are briefly discussed.

The discussion focuses on elements that affect the quality of the data collected by travel simulators. In particular we examine the following issues:

1. Purpose of travel simulator and subjects' task;

2. Description of simulator which includes the computer environment, user interface (such as simulation of travel task, information provided to the travelers, and post trip information), network performance (such as type simulation of network characteristics, generation of link performance characteristics, and simulation of stops and delays), and guidance generation;

3. Experiments and data analysis methodology;

4. Overall evaluation of simulators. The discussion about their advantages and disadvantages addresses issues of the appropriateness of these simulators for data collection and model building.

3.1 Kyoto University, Japan

The simulator developed at Kyoto University is described in Iida *et al*, 1992a, 1992b, and 1993.

3.1.1 Purpose of Simulator and Travelers' Tasks

The main purpose of the simulator described in Iida (1992a, 1992b) was to collect data in order to evaluate the effects of past experiences on route choice. The simulator cannot be used to examine en-route diversion behavior in the presence of information. The focus is on day-to-day route choice dynamics (pre-trip planning). Each subject must perform sequential trips; for each trip he/she must select a route and predict the travel time to the destination. A newer version of the simulator currently under development will include en-route dynamic traffic information (Iida, 1993).

3.1.2 Description of Simulator

Computer Environment

The simulator runs on PCs and mainframes.

User Interface

- **Simulation of travel and driving task**

  The travel task is simulated by using the computer keyboard. By pressing the keypads, the subjects choose their route to follow and the predicted values of travel times on the alternate routes.

- **Information provided to the travelers**

  Currently, variable message signs are the only source of information to travelers. This information is displayed by numerical characters. Only the travel time delay resulting from the incidents is presented to the travelers.

- **Post-trip information**

  The travel time on the chosen route is provided to the travelers at the end of each trip.

Network Performance

- **Simulation of network characteristics**

  The network is fixed and consists of one origin-destination pair connected by two distinct routes.

- **Generation of link performance characteristics**

  Two different models are used to generate link travel times. The first considers a conventional link performance function which is used to generate travel times based on participants' choices. The travel time is calculated endogenously by aggregating the participants' choices. The second model uses a macroscopic dynamic traffic flow simulation.

- **Simulation of stops and delays**

  Stops and delays are not explicitly modeled. The route travel time includes delays at intersections.

Guidance Generation

The initial version of the simulator provided no guidance to the travelers. In the latest version, guidance is updated every minute. Current or predicted traffic conditions are provided. The reliability of the information can be controlled.

3.1.3 Experiments and Data Analysis Methodology

The results presented here were obtained using the original version of the simulator (pre-trip planning).

Two different experiments were conducted. In the first experiment subjects were presented only with the actual travel time of the last trip. Forty subjects were used, each making 20 consecutive trips. The purpose of the trip was to commute to work during the morning's peak period (lasting one hour). The choice objective was to reach the destination as soon as possible.

In the second experiment, subjects were provided with the whole history of both predicted and actual travel times. Subjects were asked to predict the travel time on both routes for the next trip and to choose the route for their next trip:

The following data was collected for each subject.

- socioeconomic characteristics;
- attitudes and perceptions about trips;
- network performance statistics;
- information provided;
- route choice; and
- response to guidance.

A regression model was used to model the updating of travel time perceptions from trip to trip. The dependent variable was the correction value for predicted time for the trip to follow (predicted travel time for the *n+1* trip minus the actual travel time in the n trip), regressed on the prediction error of travel time at the previous trip (predicted travel time for the n trip minus the actual travel time in the n trip).

The following conclusions were reached using the data collected by the simulator and the model described in the previous sections:

- The amount of information regarding past experience and travel times on the two alternatives (number of previous trips) affects route choice behavior.

- Route switching behavior varies depending on the characteristics of the route and differs among individuals. Four different types of switching behavior were identified: a) travelers that stay in the preselected route independent of traffic conditions encountered or information provided, b) travelers that tend to choose a specific route on which they return even after a diversion, c) travelers with a moderate frequency of route switching, and d) travelers with high frequency of route switching.

- Route switching rate increases as the actual time and the predicted travel time error increases.
- The relationship between an error in the predicted time and the adjustment from the actual travel time to the next predicted time is almost linear. Furthermore, if the actual travel time is longer than the predicted one, the next step's predicted travel time is corrected so that it becomes smaller and vice-versa.

- The predicted time error in the last trip is more significant than all the others corresponding to previous trips. This coincides with the results of Chang and Mahmassani (1988), who suggested that the most recent experience has the greatest effect on travel time.

3.1.4 Discussion

The main advantages of the simulator are its simplicity (from the user point of view), its low computational costs and its lack of special hardware requirements.

However, since the purpose of the simulator is the investigation of travelers' reaction with respect to travel time (all other stimuli are ignored), the network representation and the travel task are very simplified. The simulator incorporates no features to simulate a realistic travel environment.

The simplistic nature of the simulator might result in significant biases in the experimental results. For example, as the authors state, it was found difficult to maintain participants' interest in the experiment. Moreover, the authors identified an overreaction to the travel time changes although this bias was not quantified. Finally, the use of a convenient sample for subjects (college students) raises questions about the validity of the conclusions.

3.2 Massachusetts Institute of Technology

The simulator is described in Koutsopoulos *et al*, 1993.

3.2.1 Purpose of Simulator and Travelers' Tasks

The simulator developed at MIT can be used as a tool for collection of data in order to construct models on travelers' route choice behavior in the presence of information. Each subject has to drive from a specified origin to a specified destination, and make pre-trip and en-route decisions regarding their route.

3.2.2 Description of Simulator

Computer Environment

The simulator runs on PCs.

User Interface

- **Simulation of travel and driving task**

  A *driving/observation* window shown on the PC screen corresponds to the travel task. At each intersection, the traveler must click on the mouse and choose the next link to follow based on the available information. The traveler is provided with the following information en route:

- a birds' eye view of the network (optional);
- view of the car moving on a link and stopping at intersections (with red light on);
- the status of traffic lights on a link ;
- the direction of destination, shown continuously by a compass arrow; and
- the distance from the approaching intersection.

The following features have also been included to make the travel task as realistic as possible:

- In order to focus and hold the traveler's attention on the travel task, the traveler must keep a randomly moving ball within the car frame. Therefore, the traveler is forced to make decisions and to process all available information while "driving".
- While traveling on a link a sound proportional to the congestion level is heard.
- Current time and time elapsed are shown.
- Time advances in real time at intersections.
- Time spent on links is proportional to the travel time sampled for the link. A proportionality factor between 0 and 1 is chosen by the user.

- **Information provided to the travelers**

  The *information* window communicates traffic conditions from various information sources such as:

  - **Roadside displays and broadcasting systems:** in this scenario, messages are displayed about incidents and extreme traffic conditions.

- **Next link to follow recommendation:** an arrow showing the recommended link is displayed.
- **Network congestion levels:** the congestion levels on each link are represented with different colors. When an accident occurs its location is shown on a map.
- **Shortest path recommendation:** a dashed line, indicates the shortest path.

The reliability of information provided can be controlled by the researcher.

- **Post-trip information**

  The following information is collected at the end of the trip:

  - traffic conditions during the trip;
  - incidents;
  - decision time and route choices made at each intersection.

  The following information is provided to the travelers:

  - total travel time;
  - total decision time at nodes;
  - a score showing how well the subject did compared with the best alternative;
  - a safety score, showing how well the subject performed his travel task; and
  - the degree of compliance with the recommendations.

Network Performance

- **Simulation of network characteristics**

  Any network can be used. Intersections (signalized, unsignalized) and their control are also inputs.

- **Generation of link performance characteristics**

  The link travel times are assumed to be independent random variables sampled from appropriate distributions whose parameters vary over time.

- **Simulation of stops and delays**

  The intersection performance characteristics include mean queuing time and variance. A probability that the vehicle will be stopped is associated with each intersection. If a sampled random number indicates that the vehicle has to stop, a delay is added.

- **Generation of incidents**

  Incidents are sampled from predefined frequency distributions. The type of incidents (major or minor) and their durations are sampled as well.

Guidance Generation

The guidance is user specified and the frequency of update and reliability of the information provided can be controlled by the researcher.

3.2.3 Experiments and Data Analysis Methodology

Koutsopoulos *et al* (1993) used the MIT simulator to collect data and model the route choice process and the travelers' perceptions in the presence of information by using concepts from fuzzy sets theory, approximate reasoning and fuzzy control.

Ten subjects participated in the experiment; each performed 20 trips under various traffic conditions (congestion levels, incidents, etc.) A real network was used and the subjects recruited were actual commuters in this network. Data collected included:

- Prior travel time perceptions for different alternatives, individual choice sets, and socioeconomic characteristics based on a preliminary interview session.

- Observed traffic conditions while travel.

- Available pre-trip and en-route information.

- Choices made.

The case study demonstrated that subjects were able to act realistically by associating trips made using the simulator with actual trips. It also revealed that traffic conditions on one path might affect the attractiveness of an alternative path. The results of the case study also supported the a priori hypothesis that human reasoning concerning route choice is simple and can be captured by rules of thumb.

3.2.4 Discussion

The main advantage of the MIT simulator is its flexibility to model various operating scenarios:

- The non-fixed network representation provides the chance to identify the effect of different types of networks (real or hypothetical, familiar or unfamiliar, simple or detailed) on travelers' behavior.
- The variety of information provided present the opportunity to study the effect of various types of ATIS on travelers' behavior.

The simulator allows the investigation of pre-trip, en-route and departure time choices under the provision of ATIS.

Given that the simulator runs on PCs, the travel task is as realistic as possible since special features have been incorporated to keep travelers' attention focused on the travel task. Finally, the simulator has low computational costs and no special hardware is needed.

The main disadvantage of the simulator is its simplified graphical representation of the network. Moreover, there are no interactions with other cars in terms of graphical displays.

3.3 Systems Technology, INC and JFT Associates, CA

The simulator developed by Systems Technology, INC and JFT Associates is described in Allen *et al*, 1991a, 1991b, 1991c, 1991d, in Rathi *et al*, 1993 and in Allen, 1993.

3.3.1 Purpose of Simulator and Travelers' Task

The purposes of this travel simulator are: 1) to identify the responses of travelers to in-vehicle navigation systems when confronted with traffic congestion and 2) to access the potential traffic benefits that can be gained through the use of in-vehicle navigation systems. The travelers' task was to decide when to divert from the freeway to an alternative route in order to minimize trip delay. To motivate these decisions, travelers were given rewards and penalties according to their performance in minimizing trip delays and predicting traffic.

3.3.2 Description of Simulator

Computer Environment

The computer environment is comprised of:

- A slide projector which displays traffic environment images. The slides show an out-the-window view which includes traffic conditions and roadside displays and a partial instrument panel with a speedometer, odometer and digital clock.
- A PC and a color monitor that control the navigation system's visual displays and auditory stimuli and also record subjects responses.

User Interface

- **Simulation of travel and driving task**

  The traveler is provided with a specialized keypad to answer questions, indicate diversion decisions, and designate alternative routes.

- **Information provided to the travelers**

Four different types of in-vehicle navigation systems were simulated:

1. *Static Map System*: A descriptive one-way communication system with simple directional aids and a map system. No traffic information is provided to the subjects.

2. *Dynamic Map System*: A descriptive one-way communication system with simple directional aids, map system, and with capability of indicating congestion areas.

3. *Route Guidance System*: A prescriptive two-way communication navigational system between the vehicle and the control center which indicates to the subject the best route.

4. *Advanced Experimental System*: A prescriptive two-way communication system similar to the route guidance system, with the additional capability of map display and directional aids. It provides highlighted alternate route designation and a textual display bar which defines congestion conditions, amount of delay, alternate route suggestions and auditory instructions to reinforce the visual display information.

The following information was also displayed: the congestion level ahead, its cause, expected delay, and destination arrival time.

The difference between the Route Guidance System and the Dynamic Map and Advanced Systems is that the former provides only diversion recommendations.

- **Post-trip information**

The simulator keeps track of those travelers who diverted from the freeway and asks them about their intention to return to the freeway. Based on the travelers' performance a reward/penalty payoff is calculated.

Network Performance and Guidance Generation

Slides were presented every 5 seconds showing an out-of-vehicle screen including freeway traffic and guide signs. Three different incident levels were defined with 11-minute, 18-minute and 30-minute delays. Traffic incident severity involved two factors: a) number of lanes blocked and b) arrival time to the destination.

3.3.3 Experiments and Data Analysis Methodology

The objective of the experiment was to compare the effect of various experimental navigation systems on traveler route diversion and alternate route selection.

The experiment conducted included 4 phases:

1. **Phase 1**: Pre-questionnaire, which covered socioeconomic characteristics and commuting behavior.
2. **Phase 2**: Training
3. **Phase 3**: Actual experiment with scenario description, travel task, subjects' route choice, and feedback to the subjects.
4. **Phase 4**: Post-questionnaire, which gathered information about past diversion behavior, factors affecting diversion behavior to avoid congestion, acceptable delays and human factors issues of various navigation systems.

A traffic flow simulation model was also developed. The objective of the simulation analysis was to determine the consequences of travelers' decisions on traffic network congestion and to evaluate the effectiveness of in-vehicle navigation systems in reducing congestion. The population consisted of familiar and unfamiliar vehicles and vehicles with access to ATIS. The behavior of various types of vehicles was based on the results of the experiment described above.

The following conclusions were drawn from the conducted experiment:

Navigation system configuration strongly influenced diversion decisions for all congestion levels. The display of congestion information had some effect on route diversion response, but the most significant effect was achieved with the provision of alternate route recommendations. At the initial stages of the experiment, when the recommendation was to divert from the freeway compliance was found to be moderate (40 to 60%).

The compliance rate was high when the Advanced Experimental and Route Guidance system were used (70% to 80% compliance). Travelers equipped with Advanced Experimental and Route Guidance systems were more responsive to changing traffic conditions than the Static Map and Control groups. The Dynamic Map group fell somewhere between the two groups in diversion responsiveness.

Diversion behavior was significantly affected by age. The older age group (55 years) was less willing to divert than younger subjects. Subjects' gender and route familiarity did not affect diversion behavior.

Diversion behavior was clearly affected by congestion conditions (i.e. amount of delay).

3.3.4 Discussion

The main advantage of the simulator is the realistic representation of the travel environment, since the traveler faces pictures of a real network with actual travel conditions. Moreover, the simulator gives the opportunity to study the behavior of people under a wide variety of ATIS, and therefore provides the necessary background to perform relevant evaluations.

Theoretically one can input any type network, but from a practical point of view it is difficult to modify the existing one in order to test other configurations (such as different networks to different subjects). This might cause some rigidity to the experiments conducted. Moreover, the Map Display shows congestion levels on freeways only. Subjects might exhibit different behavior if congestion levels were provided for the entire commuting network, subjects might exhibit different behavior.

A major advantage of the experiment conducted was the recruitment of subjects of all age categories, commercial and uncommercial travelers, some familiar with the area of the experiment, some not. The main disadvantage of the experiment performed is that the goal of travel is not variable. As the authors note, the emphasis of the experiment was diversion to avoid traffic congestion, therefore subjects could be over motivated in their diversion response. Additional experiments under different instructions should be performed.

A fully interactive, continuous vehicle control simulator has since been developed (Allen, 1993). The main characteristics of this version include:

The simulator runs on IBM compatible PC's. The travel task is simulated by using a vehicle control mathematical model and updated animated graphics. All types of information can be provided to the travelers (VMS, next link to follow and shortest recommendations, congestion levels on links and traffic scenes). To make the user interface more realistic, steering, speed control, and interacting traffic have been included in the simulation. Any type of network can be simulated. Further modifications of the simulator will include a combination of the two simulators described above, steering and speed control, and information/navigation tasks and displays.

3.4 TNO Institute for Human Factors

The simulator developed at the TNO Institute for Human Factors is described in Richard van de Horst, 1993. The experiments conducted are briefly described in Van der Mede and Van Berkum (1991). A parallel travel simulator experiment is also described in the above paper.

3.4.1 Purpose of Simulator and Travelers' Task

The TNO simulator was developed to enable human factors research, such as optimization of new road designs, travel under poor visibility conditions (fog), assessment of variable message signs, and assessment of in-vehicle information systems. In the experiment conducted in 1991, the travelers were instructed to choose between two alternative routes to go to work while information from VMS was available.

3.4.2 Description of Simulator

Computer Environment

The simulator runs on a modular system consisting of three computers. The first is in charge of overall supervision of the experiment; the second simulates vehicle dynamics; the third provides the real-time computation of the out-of-vehicle visual environment.

User Interface

- **Simulation of travel and driving task**

  The travel task is simulated by placing the traveler in a fixed-base mock-up with all controls such as steering wheel, pedals, etc. Driving is simulated realistically with steering force, gas-pedal force, speedometer, in-vehicle displays, etc.

- **Information provided to the travelers**

  The visual scene computer can simulate various forms of VMS displays, next link to follow recommendations, and congestion levels on links. Other traffic of up to 64 moving objects is also displayed. Three projectors display the visual scene on a screen in front of the mock-up.

- **Post-trip information**

  The post-trip information provided to the travelers includes travel-times, arrival times, speeds, etc.

Network Performance

- **Simulation of network characteristics**

  Any type of network can be simulated.

- **Generation of link performance characteristics**

  Link performance characteristics (travel times, stops, delays) are strongly dependent on the scenario to be implemented.

- **Generation of incidents**

  No information on incidents is currently available.

Guidance Generation

The guidance provided to the travelers through VMS strongly depends on the scenario to be implemented.

3.4.3 Experiments and Data Analysis Methodology

In the experiment conducted subjects were instructed to choose between two routes entering the beltway around Amsterdam. The purpose of traveling was to get to work and subjects were charged with a fine if they arrived late. The experiment involved 48 subjects, each performing 60 trips. Route 1 was normally advised, when the VMS was operational, route 2 was advised. The subjects' trips were recorded. No information about the experimental methodology and results obtained has been available.

3.4.4 Discussion

The TNO simulator is a very realistic simulator since the travel task is conducted in a vehicle mock-up. Moreover, the complex visual scene is updated with a high frequency rate. A disadvantage of the design (that may affect subject's behavior) is that the readability of road signs displayed by the simulator is poor. No explicit information about the experiment conducted or the results obtained is available, therefore no comments can be made about the validity of the simulator.

3.5 University of California at Davis

The simulator developed at the University of California at Davis is described in Vaughn *et al* , 1993 and Yang *et al*, 1993.

3.5.1 Purpose of Simulator and Travelers' Tasks

The purpose of the simulator was to collect route choice data under the influence of ATIS. Travelers were instructed that their objective was to minimize travel time by deciding when to follow the ATIS recommendation. Travelers were told that they had purchased a "Traffic Watch Device" which provided them with traffic information for two alternative routes before the beginning of their trip. However, unknown to them, the accuracy of the traffic information varies. Subjects were also told that their decisions and response times were measured, and that they should try to correctly respond as quickly as they could.

3.5.2 Description of Simulator

Simulator Environment

The simulation experiment was carried out on an IBM compatible micro-computer.

User Interface

- **Simulation of travel and driving task**

  The travelers decide between the freeway or a side road. When the keyboard's space bar is pressed, the system's advice appears on the screen. The traveler has only to decide which route to follow. The mean speed of the chosen route is represented indirectly by the speed at which the cursor (representing the car) moves.

- **Information provided to the travelers**

  The following information is provided to the travelers:

  – A birds' eye view of two parallel links, one representing the freeway and one the side road;

  – The Advice, which consists of two messages: a) a suggestion of the route to follow, and b) the traffic conditions on the indicated route.

- **Post-trip information**

The post-trip information consists of the travel time on both links for a specific day and the chosen route.

3.5.3 Experiments and Data Analysis Methodology

Three different experiments, employing groups of 23, 25, and 29 subjects, were performed. Each subject made 32 trips. The first experiment was conducted to investigate the accuracy requirements of ATIS. Three different levels of accuracy were provided: 60%, 75% and 90%. In the second and third experiments the accuracy of the advice was held constant at 75% but other conditions were varied. All subjects were undergraduate students at University of Davis.

The following information has been collected:

- route advised by the information system;
- delay on the freeway;
- delay on the sideroad;
- route choice of each subject;
- individuals' level of satisfaction with the choice made;
- decision time;
- personal characteristics of travelers;
- percent accuracy of advice given;
- acceptance rate of advice.

Analysis of Variance (ANOVA) models were used to analyze the data collected. This approach was chosen because it makes no assumptions about the relationship between dependent and independent variables, and it does not require the independent variables to be quantitative. Three dependent variables were selected for analysis:

1. The travelers' willingness to accept the advice provided by the information system.

2. The subjects' decision time (number of minutes the traveler takes to decide which route to follow when information is given to him).

3. The subjects' potential use of the type of information system he/she used in the experiment.

To model sequential route choice behavior two different modeling approaches were proposed. The first approach consisted of a conventional logit model formulation. The perceived utility for each alternative was influenced by attributes of the alternative, the individuals' characteristics, information available on the alternative, accuracy of the above information, and a habitual variable. The second modeling approach used concepts from neural modeling.

The following results were obtained from the ANOVA models:

1. The willingness of subjects to follow the advice provided depends on the accuracy of the advice, experience level of the traveler, traveler's gender, and the advised route.

    - The accuracy of the advice has a strong effect on the average acceptance rate of the advice.

    - The learning effects over time do not have a significant effect on the average acceptance rate of the advice

    - Initially travelers' are predisposed to follow the systems' advice but they rapidly identify the information's accuracy level and adjust their behavior accordingly. Moreover, an *accuracy threshold* does exist above which the travelers follow the systems advice and below which they reject it.

    - Men are more prone to follow the advice given by the system than women.

    - Subjects tend to prefer the freeway to the local routes. This preference was termed *freeway bias* by the researchers. "Freeway bias" could be explained by the limited choice set of alternative routes and the lack of opportunity to switch between the two alternatives.

2. Subjects' decision times were found to be significantly influenced by the accuracy of advice, gender, advised route, travel frequency and experience with the system.

   - Subjects tend to make quicker decisions at high or low levels of information accuracy.

   - Subjects have longer decision times when they are advised to follow the side route.

   - Males and experienced travelers take less time to decide what route to follow.

   - The decision time decreases as experience with the system increases.

3. The potential use of the information system was mainly influenced by the accuracy of advice, gender, and travel frequency.

   - The more accurate the advice, the more prone travelers' are to purchase the required equipment.

   - Females are more willing to purchase such a system than males.

   - Frequent and experienced travelers are more willing to purchase an information system.

The following conclusions were drawn from the analysis of the results from the logit models:

- The probability of a route being chosen increases when the system's advice is to follow that route.

- As the perceived delay on a route increases the probability that this route is chosen decreases.

- As the accuracy of the system increases, the probability of following the advised route increases.
- The "freeway bias" is again present in these models.
- Previous experiences have little effect on current choices. This was attributed by the researchers to a probable mis-specification of the model used for "information updating".

From the neural network modeling methodology the following results were obtained:

- The neural network model was found to reasonably predict travelers' route choice.
- There exists an extensive diversity and variety of dynamic route choice behaviors among individuals and types of roads.
- Subjects differ in their ability to remember previous route choices and update their knowledge in different ways. However most subjects make route choices based on their most recent experiences. Therefore the relative accuracy of the information provided plays an important role on the immediate choices.

3.5.4 Discussion

The main advantages of the simulator are its simplicity from the user point of view, its low computational costs and its lack of special hardware requirements. The primary disadvantage of this simulator is its simplistic network representation. Subjects can only choose between two alternatives, the freeway and the side road, at the beginning of their trip. Moreover, it does not allow a study of the switching behavior between the two routes, which is a common phenomenon in real world situations. Thus, it is restricted to studying only the pre-trip planning and choice behavior of travelers according to different levels of information accuracy. With this simulator only the effect of the reliability of the advice given on travelers' decisions can be tested. The effect of different types of information systems cannot be investigated. In a real environment, these factors play an important role on travelers' decisions.

The following comments are related to the experiment conducted:

- Although the data collected may lack reliability, significant efforts of modeling travelers' behavior under ATIS have taken place.
- A disadvantage of the conducted experiment was the use of a convenient sample, consisting only of undergraduate students. The use of this sample renders questionable the general validity of the conclusions related to effects of socioeconomic characteristics on travelers behavior.

It is not clear from the paper how travelers make choices when they have no indication, other than the system's advice, of the traffic conditions on the two alternative routes. Nor is it clear how they evaluate the accuracy of the advice given.

3.6 University of California at Irvine

The simulator named FASTCARS (Freeway and Arterial Street Traffic Conflict Arousal and Resolution) developed at University of California at Irvine is described in Adler *et al*, 1992a, 1992b, 1993a and 1993b.

3.6.1 Purpose of Simulator and Travelers' Tasks

FASTCARS was developed in order to provide a platform for studying traveler behavior under ATIS technologies and to collect data for estimation and calibration of predictive models of traveler behavior under the influence of real-time information. Each traveler is presented with 5 different travel objectives and is asked to perform pre-trip and en-route travel decisions (such as goal specification, route choice, lane changes, use of information technologies, etc.).

3.6.2 Description of Simulator

FASTCARS simulates basic traveler decisions such as goal formulation and route choice and emulates three ATIS technologies: variable message signs, highway advisory radio, and in-vehicle navigation systems.

Computer Environment

The simulator runs on PCs.

User Interface

User interfaces are built around four elements: a network viewer, a control panel, a roadside information viewer, and an in-vehicle navigator.

1. *Network viewer*: Subjects are provided with a bird's eye view of the road section. Cars are able to switch lanes designated for varying speeds.

2. *Control Panel*: The control panel provides the following system information: current time, car speed, and accumulated scores for each of the five travel goals (explained later).

- **Simulation of travel and driving task**

  The cars are displayed as small rectangles. The traveler can change lanes or routes. The lane change is performed by a single keystroke. When travelers want to change route, they must first move to the correct lane and then indicate the turning direction with a single keystroke. The simulator allows pre-trip and en-route decision making.

- **Information provided to the travelers**

  During a trip travelers can access maps from the hard disk. According to the travelers' level of familiarity with the network (novice, intermediate, expert) different types of maps are presented to them. The maps differ in level of detail in network representation.

The information given about traffic conditions on the links depends on the traveler's level of familiarity with the network. Subjects familiar with the network are provided with more detailed maps than those unfamiliar with it. Expert travelers are also provided with incidents.

In addition, the following information is presented on the screen:

- Variable Message Signs (VMS), next exit, and roadside information;
- Next link to follow as part of In-vehicle Navigation Systems (IVNS);
- Shortest path recommendation through IVNS; and
- Highway Advisory Radio (HAR) through voice board.

Variable message signs are displayed at certain freeway locations, providing subjects with reports on the traffic condition of the current link. Highway advisory radio provides information on traffic conditions and availability of alternate routes. In-vehicle navigation systems give the subjects instructions to follow the shortest path. The following information can be provided if IVNS is activated: 1) suggested action for next intersection or freeway exit, 2) expected shortest travel time to destination, and 3) distance from destination.

The VMS and Roadside information is conveyed through text. The IVNS is conveyed through text and graphics (arrows pointing to the direction of the shortest time path). The HAR uses a Voice Adapter which allows subjects to activate pre-recorded radio messages containing information on traffic conditions and availability of alternate routes.

- **Post-trip information**

After each trip a scoring based on traveler's travel objectives is presented.

Network Performance

- **Simulation of network characteristics**

Currently, any type of network can be simulated. The network is specified by the designer and the data is stored externally.

- **Generation of link performance characteristics**

  Link performance characteristics are generated by specifying the mean speeds in the link files.

- **Simulation of stops and delays**

  Calculation of delays due to lane switching is performed. Moreover, signals operate according to some plan and when cars reach an intersection with a red light they stop and queue until the light turns green.

- **Generation of incidents**

  Random incidents are assigned to links. The incidents are characterized by the starting time, duration, severity and the corresponding link speed.

Guidance Generation

All the generated information is constantly updated and always reliable. Each time the traveler enters a new link FASTCARS calculates the shortest path to the destination. HAR is prepared based on the generated network profile.

3.6.3 Experiments and Data Analysis Methodology

In the case study 27 participants performed 108 trials. The subjects were required to make choices such as goal specification, route and lane changes, and whether or not to use information technologies. A hypothetical network (comprised of freeways and arterials) was used in the experiment. The experiment consisted of three parts: pre-trip planning, en- route travel and post-trip evaluation.

1. **Pre-trip planning**

   In this stage subjects select travel objectives and the initial route to follow. The objectives are formulated by assigning weights to the following goals:

   (a) arrive at destination 20 minutes earlier;

   (b) minimize travel time;

(c) minimize number of stop lights encountered;

(d) minimize number of road changes; and

(e) minimize trip distance.

The collection of socioeconomic characteristics and travelers' attitudes and perceptions can be programmed into the pre-trip planning.

2. **En-route travel**

   The data collected during the experiment include presence of VMS, HAR, IVNS, initial route choice and route diversions during trip in response to guidance.

   The data analysis effort focuses on factors affecting en-route diversion, estimation of models for information acquisition (when ATIS is activated), and longitudinal analysis of repeated trips to study the learning effects.

   Two alternative modeling approaches were used. One was based on a a utility maximization approach (logit and probit estimations) for primary and secondary diversion behavior; the other was based on conflict resolution concepts to model travelers' route choice behavior. According to this approach, when conflict rises to a level that exceeds a personal threshold of tolerance, travelers are likely to alter en-route behavior by either diverting to an alternative or by revising their goals.

3. **Post-trip evaluation**

   An evaluation of the travelers' trip, based on their goals, is provided after each run.

Preliminary analysis showed that en-route diversion behavior is influenced by familiarity of travelers with the potential alternative routes and their traffic conditions, information provided by the VMS, changes in travel speeds, and travelers' risk preferences. Moreover the value of information decreases among more experienced travelers.

3.6.4 Discussion

A major advantage of FASTCARS is the program's flexibility and completeness. It combines a real-time simulation program using a graphics-based interface with visual and audio effects to imitate travel conditions. A second advantage is that it realistically represents the entire travel process from pre-trip planning through arrival at destination. Players are required to make a broad range of choices which include goal specification, route and lane changes, and active acquisition of available information systems. Additional advantages of the simulator are its portability and the wide range of information systems that can be simulated.

A major disadvantage of the simulator is that players are provided with only a bird's eye view of a road section and not a whole picture of traffic conditions for the network. this means their decisions are based on incomplete information. Furthermore, since the information provided by the IVNS is always reliable, no inference can be made on travelers' behavior under provision of unreliable information. Finally the interactions with the system via keyboard and mouse do not provide a travel sensation (no special features have been added to make travel task more realistic).

The results of the experiment, which used a hypothetical network, may differ significantly from results which may have been obtained using a real network. Although travel in a hypothetical network facilitates the study of "familiarity" as a variable, it differs considerably from travel in a real network. Finally, a bias that was observed during the experiments was that first-time players were more likely to divert than experienced players and try new routes in response to minor delays.

3.7 University of Leeds, England

Three different simulators have been developed at the University of Leeds, IGOR 3-D a newer version of IGOR and VLADIMIR (Bonsall 1992 and 1993) and TRAVSIM developed by P. Firmin (1993a).

Bonsall and Parry (1991) were probably the first to develop an interactive route-choice simulator (IGOR - interactive guidance on routes) for the purpose of investigating factors that affect travelers response to route guidance advice. In their experiments, users were invited to make a series of trips through a hypothetical network from one intersection to the next on the way to their destination. Conditions in the network varied from day to day and differed according to the time of day. At each intersection, IGOR displayed a plan of the intersection annotated with information about road sizes and alignments, signposts, current traffic conditions etc. For some trips the user had access to a map and/or guidance advice. However, "wrong" exits were sometimes recommended in order to see the user responses to unreliable information. The results showed that the acceptance of an advice varied with the objective quality of the advice, quality of the previously received advice, local conditions and psychological factors. The influence of the travelers' knowledge of the network and of the existence of corroborating or conflicting evidence was also demonstrated. Note that IGOR was launched in 1990. By mid 1991 a total of 700 subjects had participated in the experiments. On average guidance advice was accepted on 70% of occasions, although it was related to the quality of the advice. It was also found that in unfamiliar networks subjects accepted guidance information on 10% more occasions. (Firmin, 1993b)

Three recently developed simulators, IGOR 3-D, VLADIMIR, and TRAVSIM will be reviewed in this study.

Purpose of Simulators

IGOR 3-D and VLADIMIR were developed as tools to study the impact of new in-car technology on travelers' behavior. More specifically, the simulators were used to study the following issues:

1. Appropriate message content and message presentation for a range of situations, particularly:

    - information on expected delays ahead or on expected journey times to specified locations;

- information on the source for reported delays (eg. accident, congestion, road works etc.); and
- directional advice to destinations.

2. Traveler responses to cost differences between alternative routes.

3. Responses of different types of travelers (familiar, unfamiliar, etc.).

4. Impact of the quality of both present and previous information.

3.7.1 IGOR 3-D

Computer Environment

IGOR 3-D is designed to run on color PC.

User Interface in an animated 3-D road view is presented on the screen, with "speed" proportional to that on the current link. Signs are visible in the 3-D road view. The dashboard shows speed, elapsed distance and current time.

Network Performance

A hypothetical network which consists of 50 links (all intersections are signal controlled) is currently used. Position of the sun in the sky and the shadows of buildings can be used to deduce direction of movement. Current road conditions are overprinted on the road view. Traffic condition scenarios are exogenously defined.

Guidance Generation

The in-vehicle guidance/information is provided by text or symbols on a panel on the dashboard (VMS are superimposed over the 3-D road view). The reliability of the guidance may vary.

Experiments and Data Analysis Methodology

A standard session includes a training trip and then 10 further trips in different scenarios between different points or in different networks. It also includes a questionnaire to obtain background information on the subject and his/her route choice behavior. Analysis of data (conditions met, decisions taken and responses to questions) is conducted exogenously. No information on data collected with IGOR 3-D is currently available.

Discussion

The simulator is a powerful tool to conduct controlled studies of traveler route choice, with and without various forms of information and guidance available. It is the successor program to the original IGOR providing a much more "realistic" travel experience and a clearer differentiation between the in-car and on-road scenes.

3.7.2 VLADIMIR

The purpose of VLADIMIR is to explore traveler route choice with and without the provision of information and guidance available (turning advice) and to explore the effect of familiarity with the network on route choice and compliance. It replicates journeys in real networks by allowing the travelers to navigate from a given origin to a given destination by pressing the appropriate key arrows at junctions. Travelers can perform (legal) turns at intersections, ask for (hard copy) map, receive information and turn advice etc. Each traveler is given a trip purpose and a target arrival time.

There exist two versions of the VLADIMIR. The simplest version provides only VMS facilities.

Computer Environment

The simulator runs on PC's.

User Interface

- **Simulation of travel and driving task**

  Travel task is simulated by travelers' choices at each junction, decisions to drive past upcoming minor roads, and to stop the vehicle to consult a map. Progress on link is shown on scrolling plan.

- **Information provided to the travelers**

  The dashboard shows speed, elapsed distance and time, next link to follow recommendations, congestion levels on links, and information on incidents. The information is conveyed through colors, text, symbols, sound and digits.

- **Post-trip information**

  The post-trip information provided to the subjects is arrival time at destination and distance traveled.

Network Performance

- **Simulation of network characteristics**

  Real networks can be used, with a typical size of 500 links (networks have been set up for Leeds, UK and for Aalborg, Denmark) with max 700 two-way links. The road view is provided by a series of digitized photographs. The progress through the network is shown on a scrolling plan of immediate vicinity with the travelers' car marked on it. The scrolling plan rotates so that the car is always heading up the screen. Scroll rate is proportional to speed.

- **Generation of link performance characteristics**

  Travel times are exogenously defined with stochastic variations. Current road conditions are overprinted onto the photographs and obtained from exogenously defined files. There is a constant relationship between simulation time and time while travel. Manoeuvres at junctions are in real time (with conflicting tasks taking longer) while progress on links is in fast time. The simulation time is equal to the real time while thinking or consulting a map.

- **Simulation of stops and delays**

  Simulation of stops and delays is performed in real time. U-turns take longer than others.

- **Generation of incidents**

  The generation of incidents is stochastic and affects the travel time.

Guidance Generation

The reliability of the information provided is variable. Frequency of update and nature of information (historic, current, predicted) are specified by the researcher.

Experiments and Data Analysis Methodology

Analysis of data is done exogenously. The following data can be collected: users' socioeconomic characteristics, attitudes and perceptions, network performance statistics (as experienced by the subject), information provided, route choice, response to guidance, delays in response, use of map and familiarity with the network. Data has not been analyzed yet.

Discussion

Major advantages of the simulator are: portability, user specific network and the ability to simulate real networks. The travel task is very realistic and hence we expect that the data collected will be of good quality. However, if a real network is used, then network preparation, photographs, and travel times can be time consuming.

To overcome the risk that VLADIMIR resembles to a "game", a simplified version which does not incorporate a scrolling plan has been developed. This version provides both VMS information and next link to follow recommendations.

3.7.3 TRAVSIM

TRAVSIM is an experimental route choice travel simulator designed and developed by P. Firmin (1993a), to evaluate the effects of simulator design features such as travel tasks, information portrayals, provision of feedback and decision inducement, on travelers route choice and compliance with the route guidance advice.

TRAVSIM replicates journeys in real networks by allowing the subjects to travel from given origin to given destinations within a hypothetical town center road network and their decision responses is logged automatically by the simulator, along with the related decision time and task success.

Computer Environment

The simulator runs on PC's.

User Interface

- **Simulation of travel and driving task**

  Travel task is simulated by travelers' choices at each intersection. The subsidiary travel task if selected, positions a randomly moving ball on the periphery of the steering wheel, which the subject has to control while the vehicle is in motion. If the decision inducer is invoked, the screen displays messages of rear view mirror screen and sound a decision stress inducing "Car Horn" to simulate impatient travelers when the subject exceeds a pre-determined time limit in making a decision.

- **Information provided to the travelers**

  The simulator consists of two main window segments of information on the view screen. The first window shows a through the windscreen view of the road scene ahead including 3-D junctions and an internal dashboard panel. The second window shows a rear road scene view mirror (view of cars following). The dashboard shows mock steering wheel outline, speed, miles, next link to follow recommendations with the form of directional arrow pointer, congestion levels on links, and information on incidents. Furthermore, subjects can be provided with journey progress feedback. The information is conveyed through colors, text, symbols, sound and digits.

- **Post-trip information**

  Subjects can be provided with journey performance feedback, if requested.

Network Performance

- **Simulation of network characteristics**

  Three different road types can be simulated, motorway, principal roads and urban streets. Alternate traffic conditions scenarios can be simulated (peak hour, of peak, etc.). The simulator contains traffic signals, local and strategic road signs, and building landmarks. Junctions are limited to cross-roads and T-junctions, although it is possible to program 3 to 4 roundabout.

- **Generation of link performance characteristics**

  All traffic conditions are pre-generated and are input to the simulation program from a separate data file. Travel speed is portrayed to the subject through animated center lines, a simulated travel noise and also the speedometer needle position. Time is simulated during the travel sequences approximately 30 times quicker than normal. However, real time is employed when stationary at intersection decision-making points. The dashboard clock has been programmed to smoothly accommodate the utilization of the different time bases.

Guidance Generation

Route guidance advice and Variable Message Signs can be induced if decided. The reliability of the information provided is variable. Guidance advice is predetermined to be good at some journeys and indifferent on others (programmed to give 50% non-optimal advice). This information is contained in a separate data file.

Experiments and Data Analysis Methodology

The simulator has already been trialed on 34 subjects, and it is expected to have at least 100 subjects before the end of 1993. No experimental analysis has been conducted yet.

Discussion

The major advantage of the simulator is its flexibility, which allows the study of the effects of simulator design features on travelers' responses. The travel task is realistic, since the introduced moving ball simulates the complexity of steering tasks and hence we expect that the data collected will be of good quality.

A disadvantage of the simulator is the hypothetical network used.

3.8 University of Texas at Austin

The simulator developed at University of Texas at Austin is described in Shen-Te Chen and Mahmassani, 1993.

3.8.1 Purpose of Simulator and Travelers' Tasks

The simulator was developed to conduct laboratory experiments to examine the en-route diversion decisions, day-to-day departure time choices and route choices of the travelers under the alternative information strategies and issues of convergence to an equilibrium. The simulator is connected to a traffic simulation model and the subjects of the experiment become part of its model. Therefore multiple users can drive through the network, interact with each other and influence the systems performance.

3.8.2 Description of Simulator

Computer Environment

The simulator is implemented on Unix-based workstations.

User Interface

- **Simulation of travel and driving task**

Each subject has to travel to the Central Business District (CBD) area through a corridor network. At the beginning of their trip travelers acquire traffic information and choose their departure time and route. These decisions are fed into the traffic simulation model. At each intersection, the travelers acquire en-route information and are asked if they will continue on the same path or if they will switch to an alternative one. Information is shown on the screen; travelers can move their vehicles according to their decisions in real time using a mouse and keyboard.

- **Information provided to the travelers**

  Each subject is provided with the following information:

  - the monitor screen shows a view of the network, traffic conditions, and the vehicle's position at all times;
  - different situational messages (such as queue development) are accompanied by a "beep" when they appear on the screen; and
  - the travel time elapsed from the beginning of the trip is shown.

- **Post-trip information**

  Post-trip information includes travel time, route taken, decisions made during the trip, information provided during trip, and consequences of decisions taken. Subjects cannot obtain information on other subjects' trips.

Network Performance

- Simulation of network characteristics

  All types of networks can be simulated (networks, corridors, freeways and urban streets).

- Generation of link performance characteristics

  A time-dependent input function is used to determine the associated vehicular movements, thereby yielding the resulting trip times, including estimated delays associated with queuing at nodes.

Network performance is obtained from a traffic simulation model. Traffic consists of vehicles driven by the subjects and other vehicles whose operations are simulated. Subjects make their own decisions while the remaining vehicles adhere to one of the following route switching rules:

- under the myopic rule, they always select the fastest route, therefore switch to an alternative independent of the remaining time to reach destination
- under a bounderly-rational rule, the travelers switch from their route only if the improvement in the remaining trip time exceeds some threshold

- Simulation of stops and delays

  Stops and delays are simulated consistent with the traffic simulation model. Messages are displayed on the screen to alert subjects of their situation.

- Generation of incidents

  Incidents can be simulated by reducing link capacity for a duration during simulation.

Guidance Generation

The generated guidance is based on current conditions. The frequency of update is user-specific (currently it is set to 1 minute). The information is current and predictive, descriptive and prescriptive. The reliability of information cannot be directly controlled.

3.8.3 Experiments and Data Analysis Methodology

Three different interactive experiments have been planned. The first includes pre-trip and en-route route choice; the second includes pre-trip departure time and route choice, and en-route choice; and the last includes pre-trip departure time and route choice, real-time departure-time adjustments, and en-route choices. In these experiments, 1800 commuters depart from 6 residential sectors. The departures are uniformly spread over a 20-minute period, with loading periods of 5-minutes from each sector. Departing rates are 60 vehicles per minute for Highway 1, 20 vehicles per minute for Highway 2 and 10 vehicles per minute for Highway 3. Each subject must perform a series of trips to the CBD area with "work" as the purpose for the trip. For analysis purposes, data is collected on subjects' preferred arrival time, the latest arrival time to work, and other attitudinal questions (pre-commuting survey), pre-trip planning, departure time choice, route switching, and post-trip information. The data will be used to investigate the influence of the following factors on travelers' behavior:

- **Origin of trip.** This affects the availability of routes to switch and also the switching propensity of the travelers.
- **Percentage of vehicles equipped with ATIS.** Each simulation involves 10800 vehicles. Some of them are equipped and switch routes according to the behavioral rule described above, and some of them are not and always follow the same route. The effect of the traffic composition on experimental results will be examined.
- **Decision time constraint.** At the beginning of the trip each subject has a limited time to decide to depart. If the subject does not choose in the allotted amount of time, the he/she does not leave. By varying the time constraints one can simulate the real-life time constraints under various traffic conditions.
- **Rate of information update.**
- **Simulation time frame.** The effect of this factor will be investigated since there exist two simulation versions, one synchronous with real time and one faster.
- **Information display strategies.** The effect of three different information strategies will be examined:

Information provided during the whole trip;

Information provided at each node;

Information provided upon inquiry by the subject.

No experimental results are yet available.

3.8.4 Discussion

The simulator has several advantages. It has multi-user capabilities and allows interaction between network performance and travelers' behavior. It allows for the investigation of pre-trip, en-route and departure time behavior of the users and of day-to-day evolution of travelers' decisions under ATIS. Moreover, it incorporates transit lines as options, therefore mode choice could be eventually examined.

The simulator allows the use of different network configurations and loading patterns. Therefore a real network can be used in which travelers are familiar with the traffic conditions and alternative routes.

Some of the disadvantages of the simulator are: It simulates a limited range of ATIS. Currently the system is limited to 100 users and therefore their effect on the systems' performance is negligible (100 actual travelers out of 10800 vehicles in the simulation).

Although the interaction with the traffic simulation model is a nice feature, it adds a certain rigidity. For example, control of parameters such as information reliability cannot be easily incorporated.

3.9 Other Efforts

Several other simulators are currently under development. However, at this point very limited information on these travel simulators. In this section we briefly review these simulators.

Van der Mede and Van Berkum (1991) used a computer game to investigate route choice behavior under VMS. Their work concerned simulation and modeling of individual route choice sequences with and without information provided by variable message signs. 34 subjects participated in the experiment. They were provided with post-trip information after each trip. After developing a route choice model which incorporates route inertia and compliance to VMS, the researchers' aim was to test its accuracy in simulating individual choice series and aggregate behavior obtained by laboratory experiments. The results indicated that travel time, travel cost, variance in travel time and cost, and previous choice and VMS advice, were significant explanatory variables. Finally, the authors developed measures of reliability of information and its effect on compliance. The analysis of the data suggested that the consequences on travelers' behavior towards further acquisition of information are not as significant as expected when the ATIS does not always give the best advice.

Kantowitz *et al* (1993) used a computer-based route guidance simulator to evaluate the travelers' acceptance characteristics when the reliability of information provided varies. The experiment used a real-time video. Travelers used a touch screen to select route links and immediately video information stored on a hard disk is sent to a second computer that displays a real-time view on that link. Traffic advisory information is presented on the screen in the form of either general traffic reports (such as there is a stalled truck blocking traffic on the I-90 bridge) or can be purchased for specific links of interest. Travelers' trust to the route guidance advice and route selection is recorded, as the accuracy of information provided varies.

An advanced travel simulator is under development in University of Leeds (Carsten, 1993). This simulator makes use of the most up-to-date techniques in the creation of computer-generated animated images. The "traveler" sits in a complete car, with all the basic controls and dashboard indicators fully operational. The controls and indicators are linked to the PC, which serves as the communicator between vehicle and workstation. The car is situated directly in front of the screen with the travelers' seat aligned with the projector. The screen is designed to provide 120 degrees of view using three projectors, although currently only one projector is used. A fourth projector will eventually provide an image for the rear view mirror. The workstation continuously receives information on traveler input to the vehicle controls and re-calculates the vehicle position. The resulting traveler view, as created by the visualization software, is then projected onto the screen. The simulator is particularly geared towards research on traveler interaction with the road environment, road safety issues and the impact of new in-car technology on travelers' behavior.

Finally, using a microcomputer, Polak and Jones (1992) studied the impact of in-home pre-trip traffic information. An in-home pre-trip information system offered information on travel times from home to City Center, by bus and car at different times of day. The respondents also had the ability to generate their own choice set of alternatives through the process of information acquisition. The simulator would then provide expected travel times, parking times, and either expected arrival or required departure times. The task of the respondents was to rank the travel options displayed in order of preference. Surveys were conducted in parallel, in Birmingham and Athens. The results showed that even amongst regular car users there is a requirement for multi-modal pre-trip information. Moreover, it was found that travelers are selective in the amount and type of information they request, and that the process of information acquisition is structured according to travel preferences.

Chapter 4

Assessment of Existing Travel Simulators

4.1 Purpose of Existing Travel Simulators

Almost all of the existing travel simulators have been developed for the same purpose: to collect data in order to study travelers' behavior in the presence of information. According to their degree of sophistication, simulators are used to examine travelers' day-to-day departure time and route choices, pre-trip planning, en-route diversion decisions, and compliance rates under alternative travel scenarios (such as purpose of trips) and provision of various ATIS. The collected data can be used for estimation of predictive models of travelers' decision making under ATIS.

Some travel simulators were developed to examine the effect of simulator design on travelers' responses. These simulators offer the users a range of interfaces and specifications of travel tasks.

However, no simulator has been developed to examine the market potentials of ATIS products.

4.2 Quality of Data Collected by Travel Simulators

The use of travel simulators to obtain stated preferences data about the behavior of travelers under ATIS has significant advantages. Simulators enable the creation of a wide range of travel situations under laboratory conditions and the collection of relatively inexpensive data. For example, repeated trips conducted by the same subject present the opportunity to reduce sample size and to study the effects of learning and memory on travelers' choices.

Moreover, travel simulators are inexpensive tools for investigating how people will adopt ATIS, learn their utility, and evaluate strategies to control the use of ATIS effectively. Furthermore, travel simulators provide a safe way of obtaining data.

One of the major advantages of travel simulators is their ability to control the environment of the experiment in systematic ways. They facilitate the collection of data on travelers' behavior under different scenarios with systematic variation in road, traffic conditions, and information provided. This data is difficult or very expensive to obtain in real world experiments. For example:

- By controlling the travelers' level of familiarity with the network, it is possible to study route choice behavior and information acquisition under different cognition levels.

- By controlling the relevance and reliability of the information provided, it is possible to test travelers' behavior towards alternative types of information provided.

- The effects of new, non-existent ATIS can be tested. Therefore the design of various ATIS systems can be enhanced so that they meet the needs and the expectations of the travelers.

Moreover, the controlled nature of choice scenarios allows greater freedom in defining choice contexts, alternatives and attributes, as well as a direct comparison of the responses among individuals. Finally, measurement errors are negligible.

However, as discussed in Chapter 2, the primary disadvantage of travel simulators is that the data acquired is stated preference data, which includes biases deriving from the fact that travelers' behavior is observed in a hypothetical environment and not in real life.

In general the sources of these biases are:

1. the design of the travel simulators; and

2. the experimental set-up.

It is expected that the more realistic the design of the travel simulator is, the more likely travelers are to apply the same decision-making protocol they adopt in real-life. Therefore, the design of the travel simulator and the experimental set-up is expected to be context-specific so that the subjects respond in a familiar environment. This will help obtain reliable results.

The following sections refer to the biases caused by the design of travel simulators and the experimental set-up and suggest ways to reduce these biases.

4.2.1 Design of Travel Simulators

The design of travel simulators mainly affects the travel environment, the network representation and the information environment. In Chapter 2 the following three design aspects were identified as major factors that influence the biases in the data collected.

Travel environment

Most travel simulators are PC-based tools that utilize exclusively the computer terminal and the keyboard or keypad to input information.

It is not clear how much the degree of sophistication of a travel simulator affects the experimental results. To reduce the biases, some of the PC-based simulators use special features to maintain the attention of the subject on the travel task.

On the other hand, the dimensionality of travel simulators' graphical displays, such as 2-dimensional or 3-dimensional, plays a major role in the realistic representation of travel environment. Moreover, some travel simulators also provide auditory feedback of engine, road and wind sounds consistent with the speed of the subjects' car. The better the visual and auditory stimuli, the more the subjects are expected to use the same behavior pattern as in real life. However, Bonsall (1993b) states that more sophisticated travel simulators might reinforce the subjects' perceptions of travel simulators as "games" and therefore the results obtained will not reflect their actual decision making.

Network Representation

According to the network representation, three different types of travel simulators were developed:

1. Travel simulators in which traffic characteristics are exogenously defined and follow some statistical distributions.

2. Travel simulators which use animated representation of real networks and traffic conditions illustrated through photographs.

3. Travel simulators that interact with a traffic simulation model, so that traffic conditions are the results of the interactions among the subjects and the other vehicles in the simulation model.

The advantage of the first type of travel simulators is the flexibility they have to control all types of traffic conditions and information characteristics. However the traffic conditions might not be as realistic since it is difficult to have the appropriate distributions (correlations, etc.).

The second type of travel simulators are more realistic but the network characteristics are fixed.

Travel simulators belonging to the third category are more systematic and realistic but not as flexible. For example, they do not easily allow the control of all factors affecting travelers' behavior, such as the reliability of information provided.

Information provision

The information provided is a major factor affecting subjects' travel behavior. Two issues need to be considered. The first is how realistically the ATIS options are represented. We can identify two types of travel simulators, based on the information provided:

1. Travel simulators which display messages on the PC screen in order to simulate VMS represent traffic conditions on the links with specific colors (on maps displayed), present the shortest path with special link color, and display route guidance recommendations in the form of flashing arrows.

2. Travel simulators that project the actual network with slides and use both a PC for route guidance and shortest path recommendations and the screen wall for VMS. Subjects read actual signs while traveling and pay attention to the route guidance system.

The second issue concerns the familiarity of travelers with actual ATIS systems, and implementation of context specific differences between the real world decision making environment and the simulated environment. Hence, the results obtained may be biased since subjects make direct associations with every day life experiences. For example, they might not be able to associate the actual road VMS with the information displayed through the simulator.

Reduction of Biases Due to the Design of the Travel simulator

The following are some suggestions to reduce the biases introduced by the design of the travel simulator:

1. Efforts should be made to achieve a realistic travel environment. Therefore, special features should be incorporated and alternative configurations of each travel simulator should be tested. Moreover, if the travel simulator has the capability to display day-time and night-time road scenes and weather conditions such as snow and rain, the description of alternative travel scenarios will be

more realistic and this may result in a reduction of biases. Furthermore, most travel simulators present a bird's eye view of the network. Although this might simulate the actual behavior of travelers who choose their route according to what is termed "myopic view" (Sheffi, 1982), it is expected that a representation of the complete network might result in a different route choice behavior. In addition, the effect of the design (format and coding) of alternate ATIS options should be explicitly explored.

2. The travel simulator must be capable of generating a real network and the network representation should be general (freeways, arterials, etc.). In that case, the familiarity of the subjects with the network and the information provided could be tested since subjects could relate their choices with their actual trips. Moreover, if RP data is available, a direct comparison of the subjects' travel behavior would be possible.

3. More generally, special attention should be given to the design of the travel simulators from human factors considerations, such as good visibility or limited provision of information to avoid overloading of the subjects' short-term memory.

4.2.2 Experimental Set-Up

From the review of the experiments conducted it was found that the experimental set-up might strongly affect the results obtained. Major biases such as prominence hypothesis and preference inertia are caused by the indifference of subjects to the experimental task or by the omission of situational constraints (see also Chapter 2).

Reduction of biases due to the experimental set-up

The following are some suggestions that may be used to reduce the biases caused by the experimental design:

1. It is very important letting the subjects practice with the travel simulators before starting the formal experiment, in order to obtain efficient results. In

that way confounding effects on the results because of unfamiliarity with the simulator travel tasks, the information provide through alternative sources etc. can be avoided.

2. There is a need to provide real world factors that influence decision making, such as time penalties, risk and cost of accidents, tickets, rewards etc. These will reduce probable prominence hypothesis biases and preference inertia (such as "freeway bias"). For example, if time penalties are imposed, subjects might switch to alternatives with shorter travel times to the destination point even though they generally prefer to use the freeway or the shorter route to the destination.

3. The simulated experiment should capture different behavior under different purpose scenarios, such as trip to work or recreation. This will minimize biases caused by imperfect description of alternatives. Further, they may also reduce biases caused by the omission of situational constraints, which is an inherent characteristic of SP data. For example, when the purpose of trip is "work" and travelers have no flexible arrival time, they choose their departure time and route accordingly.

4. A representative sample of the traveling population should be used. In most of the experiments, convenient samples of students were used. However, alternate sampling schemes capturing various categories of gender, age, income, profession, etc. should give more reliable results.

5. The provision of post-trip information might change the travelers' decisions and perceptions about their route choice behavior and ATIS acquisition in future trips. This might also result in reducing justification biases (e.g. subjects learn about better alternatives and re-evaluate previous chosen alternatives).

6. In order to investigate the travelers' willingness to acquire information, the choice of information access must be made endogenous to the system. In this case, the effects of factors such as reliability and relevance of information on

travelers' information access choice process can be tested. Therefore, travel simulators should provide this capability.

The next chapter presents the conclusions and the further research.

Chapter 5

Conclusions and Further research

Although existing travel simulators are valuable in investigating the influence of ATIS on travelers' travel behavior, their contribution towards this ultimate goal is incomplete without further enhancements as discussed in previous sections. Depending on their configuration, the purpose they were developed for, and the experimental design used, all travel simulators to some degree fail to replicate actual behavior. However, due to lack of RP data, the degree of inconsistencies has yet not been quantified.

Furthermore, existing travel simulators have been developed independently of each other. Consequently, the experiments conducted cannot be directly compared. Although travel simulators represent a wide range of designs (from simple to very elaborate), the results cannot be compared in order to draw conclusions on which design is most appropriate.

Further investigation is required in order to specify the "best design". For example, a comparison of different travel simulator performance measures with the same subjects and tasks could provide a more accurate approach to identify the impacts of different travel simulator designs on the experimental results. Note that a travel simulator has been developed at University of Leeds (Firmin, 1993) to be used explicitly as a tool to examine the effects of simulator design on subjects' responses. Therefore, a range of interfaces and travel tasks have been included in the simulator.

Advanced driving simulators used for ATIS research, should be enhanced to include travel capabilities, such as a window view of the network, and be used to collect data on travel response to information provision. The results obtained from such simulators could then be compared with the results from other travel simulators. Only then the validity of travel simulators could be measured and actual modifications on the simulator design could be proposed. Note that the goal should be to have the simplest simulators that still reproduce valid results.

In addition, a modified information acceleration (IA) simulator (see also Chapter 2) could be a powerful tool to perform an ATIS demand analysis. Such a simulator would help identify the effects of different information sources (such as advertisements, magazines, word of mouth, or visit to a shop selling route-guidance systems) on travelers' awareness of alternate ATIS and willingness to pay for these systems. IA simulators would also give benefits to ATIS developers and to transportation agencies, since it would provide a better knowledge of the market place, would give estimates of the demand of such systems from purchase intentions, and forecast ATIS usage under alternative future scenarios. Moreover, the customer's voice would be heard in the design process of new ATIS as well as the customer's reactions to prototype applications of ATIS. Furthermore, an experiment conducted using a modified IA simulator, would provide us with data addressing both issues of travelers' behavior under the provision of traffic information and "market" information about alternate ATIS designs.

On the other hand, in order to validate the data acquired by travel simulators, it is important to investigate how people behave under the provision of traffic information through advanced traveler information systems in real-life. Field experiments would provide this type of data. The comparison of the revealed preference data to stated preference data will allow the enhancement of the design of the simulators. For example, as was noted before, the use of the same subjects in both field studies and simulation experiments can provide the means to identify biases introduced by travel simulators.

Finally, from modeling considerations, it is recognized that alternative data sources have different levels of accuracy and contain various types of biases. The combination of different data sources may be useful to exploit the relative advantages of each source and to obtain more reliable parameter estimates for various traveler behavior models than those of a single data source. Thus, the combination of laboratory experiments with selective field validation will be a step forward in the investigation of the impacts of ATIS on travelers' behavior, and development of models that accurately capture this behavior.

Based on the conclusions further research should cover the following topics:

1. Enhancement of existing travel simulators.
2. Design and develop extended travel simulators with IA capabilities to be used for collection of data on market behavior.
3. Use of existing travel simulators for collection of data on travelers behavior in response to information provided by ATIS.
4. Collaboration between different institutions for joint design and development of travel simulators and for exchanging both RP and SP data.

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Appendix A

Driving Simulators

This appendix provides a brief literature review of the exiting driving simulators and their current uses. Driving simulators have been used for nearly 90 years and are used as tools for work on traffic engineering, such as the investigation of drivers' interaction with road environment and road safety, to test the effects of drugs on drivers' behavior, to train policements or truck drivers, to study young drivers performance issues as a function of driving experience, to study drivers' comprehension of road signs, to evaluate the mental work load in vehicle driving and to study product design and engineering (Wachtel, 1993)

Advanced driving simulators on an ATIS context have been used to provide human factors guidelines for the design of ATIS and CVO, such as:

- examine the effects of methods for entering a destination into a route guidance system, evaluate the understanding of intersection displays at Route Guidance Systems and the impacts of ATIS interfaces on drivers' behavior;
- collect data on information requirements for the design of ATIS/CVO;
- investigate ATIS characteristics related to communicability, complexity, and consumer characteristics.

Based on the sophistication of simulator design and performance we can distinguish four classes of driving simulators (Sheridan, 1993):

1. Fixed base simulators with remotely controlled mechanical video camera carrier,presenting a scale model physical environment. These are the first developed driving simulators.

2. Fixed base simulators that present abstract line drawings or simple solid shapes that run on PC's, having linear mechanical impedance controls (springs). The average cost of these simulators runs from \$10,000 to \$20,000.

3. Fixed base simulators with realistic renderings of visual environment (SGI), having realistic mechanical impedance controls. The average cost of these simulators runs from \$100,000 to \$200,000.

4. Moving base simulators with realistic renderings of visual environment (E&S), having realistic mechanical impedance controls. The average cost of these simulators runs from \$1,000,000 to \$30,000,000.

Driving simulators have been used in accident studies and experiments in order to simulate drivers' braking behavior and relative actions in sudden and unexpected situations. Barrett *et al* (1968) used a driving simulator to investigate drivers' reaction to sudden pedestrian crosses. Atsumi *et al* (1993) used a PC to examine the mental work load in vehicle driving by analyzing the heart rate variability. Malataterre *et al* (1990) used a Daimler-Benz high performance driving simulator to observe subjects' reaction in an emergency situation at an intersection. Using a simulator to study emergency manoeuvres allowed the researchers to recreate scenarios that would have been too dangerous to experiment with in the real world. It also enabled the control of important factors affecting driver response in emergency situations and the accurate recording of both subject and vehicle responses.

Leiser and Stern (1988) used an urban driving simulator to study subjective time estimations. This simulator was computer-based, with a bird's eye view of a small segment of road with the moving vehicle on it. The driver's major tasks were to keep the vehicle on the road, make the correct choice at each intersection, and estimate travel time at the end of the trip. Traffic lights were also displayed at a number of intersections. Speed was represented by the velocity of the vehicle; the faster the vehicle the more difficult it is to keep it on the road. To study the subjective estimation of speeds, the investigators controlled the automobile speed and the drivers were asked to state the mean velocity of the car after each run.

Triggs *et al* (1993) used a micro-computer based driving simulation system to develop effective young driver risk reduction strategies. The experiment conducted aimed at identifying: 1) important differences in driving performance as a function of driving experience; 2) the relationship the driver age and experience and the attention switching time and provision of decision making information; and 3) the effect of providing likelihood alarm display (LAD) to aid the performance of the decision superimpended on simulator driving. It was found that speed variability was affected by LAD but the reaction time was unaffected.

Nilsson (1993) described the VTI simulator launched in Sweeden (1984). This advanced driving simulator with moving base has been used in a variety of studies: 1) driver behavior studies, such as influence of alcohol and drugs, hangover driving, fatigue, stress and sight; 2) vehicles studies, such as effect of sidewinds, avoidance manoeuvres, slallom driving, information systems detecting fog and mist, radar measurement of headway; and 3) road environment studies, such as road design, design and location of information systems, such as signs.

The most recent study examined the effects of driving performance from talking over a mobile phone in a car following situation. The subjects were tested over their reaction time braking, the headway allowed, the performed speed, and the perceived workload. The differences between younger and older drivers were also examined.

Hein (1993) presents a fixed-base driving simulator developed at the the Hughes Aircraft Company in 1987. This simulator is currently used for conducting Human Factors research (such as image distance requirements, specifications of disparity, etc.), product design and engineering (for example effect of design parameters on driving performance), market research and development (R&D) (such as consumer references on format, content, color and location of products) of simulation technology, human factors guidelines for ATIS and Commercial Vehicle Operations (CVO) and research related to the California Advanced Driver Information Systems (CADIS) involving concepts for route guidance and navigation. The simulator uses textured urban visual scenes with animated vehicles and pedestrians matched to map databases, houses, virtual image display, flat panel and conventional displays. It provides interchangeable driver control modules,and it is capable of a wide range of scenarios, from car-following tasks to navigation tasks to crash scenarios.

Alicandri *et al* (1993) used a fixed-base interactive driving simulator (FHWA HYSIM) to compare two versions of construction and maintenance advance flagged sign. The flagger sign was designed to alert to the motorists to the presence of a flagger in a work zone ahead. HYSIM allows the testing of traffic control devices, including signs, signals and markings in an environment that closely simulates real-world driving. HYSIM subjects attend to a wide variety of dynamic visual stimuli, control speed, lane placement, heading with vehicle ahead and perform pshycometric tasks to maintain vehicle control. The experiment conducted aimed in testing the subjects' sign recall ability, their perceptions regarding the sign meaning and required actions and their preferences between the alternative signs.

Nordmark (1992) presented an advanced driving simulator developed in Sweden with moving base intended for both heavy vehicle combinations and passenger cars. The TH-simulator is equipped with a heavy truck cab simulating heavy vehicle combinations. All instruments and equipment are retained and work in the same way as in a real truck. However, the moving base and visual system can be used as passenger cars as well. The TH-simulator is currently used for both R&D projects and for training purposes.

A simulator has been developed in the Department of Mechanical Engineering at MIT to be used as tool for human factors studies (Sheridan, 1993) . It incorporates a fixed-base car and a graphics workstation. The network provided a 4-lane highway and driving environment is very realistically represented. The above simulator can be enhanced for use in ATIS experiments.

Paelke (1993) used a driving simulator to investigate the effects of four touchscreen methods for entering a destination into a route guidance system. The following issues where examined: 1) how the destination entry interfaces compare with regard to entry time, 2) what's the effect of entering a destination on driving simulator performance, and 3) which interface method is preferred. The different interfaces resembled to actual route guidance system interfaces design used in actual field tests (such as GM's Travtek, Motorolas Advance). Participants sat in a 1985 Plymouth Laser mockup and entered a number of destination with each interface design. The driving scene was a single-lane road on which participants had to keep the vehicle centered while velocity was held constant.

Three different driving simulators have been developed at the University of Michigan (Green, 1993). The first was used as a tool to study drivers' fatigue. The second for studying the effect of traffic information displays and car phones on users behavior. The third version is a fixed-base vehicle simulator with a seat, steering wheel, foot controls, and an instrument panel. The simulator shows daytime and road scenes in color. The network is a two-lane road of any geometry, with curves, intersections, hills, and static signs. Currently only one vehicle is shown. In order to simulate traffic information a PC can be installed with graphics showing a navigation display. The traffic network cannot be controlled. In addition to route guidance the following information may be displayed on the screen: birds' eye view showing next major intersection with street names, distances and a compass heading.

Appendix B

INTELLIGENT VEHICLE/HIGHWAY SYSTEMS RESEARCH PROGRAM
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 Massachusetts Avenue, Room 1-181
Cambridge, Massachusetts 02139-4307

Moshe E. Ben-Akiva
Professor and Co-Director

Telephone (617) 253-5324
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April 23, 1993

Prof. Yasunori Iida
Department of Transportation Engineering
Kyoto University
Kyoto 606
Japan

Dear Prof. Iida:

We are working on an FHWA and Volpe National Transportation Systems Center sponsored project whose purpose is to gain data from ATIS operational tests to enhance laboratory driver simulators. Our goal is to develop a comprehensive and coordinated approach to collect data, both from demonstration projects and driver simulators, and subsequently to enhance models of the end-user response to IVHS products and services.

The key issues that will be initially addressed in the research are:

- how data from driver simulators can be used for modeling user behavior in the presence of information;
- methods to enhance data collected from driver simulators; and
- methods to augment these data with data from field tests.

The outcome of the research will benefit modelers and developers of traffic simulators since it will identify limitations of laboratory data and suggest approaches for correction of the biases introduced and methods to improve the simulation design so that the data collected is of a higher quality. Therefore, we are interested in obtaining more information about the technical characteristics, purposes and applications of existing driver simulators. To that end, we have developed a questionnaire which reflects our information needs. We plan to incorporate your response in our research report.

We would appreciate your collaboration in filling out this questionnaire and sending it to:

Ms. Amalia Polydoropoulou
Massachusetts Institute of Technology
Room 5-008
Cambridge, MA 02139
Phone: (617) 253-6309
Fax: (617) 253-0082

In the next phase of the project, we will begin funneling data from ATIS operational tests to researchers. The questionnaire will be distributed to the following researchers/developers of driver simulators:

J. Adler, University of California, Irvine

R. Allen, Systems Technology, Inc., Hawthorne, CA

P. Bonsall, University of Leeds, England

P. Green, University of Michigan

Y. Iida, Kyoto University, Japan

R. Kitamura, University of California, Davis

H. Mahmassani, University of Texas, Austin

M. Van der Vlist, Institute for Spatial Organization,
Netherlands Organization for Applied Scientific Research

If you know of anyone else who is working in this field, please let us know. Thank you for your assistance.

Sincerely,

Moshe E. Ben-Akiva
Profesor of Civil and Environmental
Engineering

Haris N. Koutsopoulos
Assistant Professor of Civil and
Environmental Engineering

MBA/ps
Enclosure

Appendix C

MIT IVHS Research Program

Review of ATIS Simulators: Questionnaire

We would appreciate it if you could answer the following questions regarding the driver simulator you are developing or have developed in the past.

1. **Purpose of simulator**

   - What was the motivation for the development of the simulator? What are its applications?

2. **Computer environment**

   - On which computer platforms does the simulator run?

3. User Interface

- How is the driving task simulated?

- What types of information can be displayed on the screen?
  - roadside displays (VMS) ________________
  - next link to follow recommendation ________________
  - shortest path recommendation ________________
  - congestion levels on links ________________
  - other ________________

- How is the information conveyed (e.g. colors, special characteristics, sound)?

- What has been included in the user interface of the simulator to create a realistic driving environment?

- What post-trip information does the simulator provide on the drivers' trip performance?

4. **Network Performance**

- What types of networks can be simulated (corridors, freeways, urban streets)?

- Is the network fixed or user specific?

- How are link performance characteristics generated in the simulation (e.g. travel times)?

- How are stops and delays at intersections simulated?

- Are incidents generated? If so, how are their characteristics incorporated (e.g. duration, effect on travel time, etc.)?

5. **Guidance Generation**

- What are the attributes of the information provided to the drivers?
  - frequency of update;
  - nature of information (historic, current, predicted);
  - reliability.

6. Data Collection and Analysis

- What types of data are collected?
  - user's socioeconomic characteristics ______________________
  - user attitudes and perceptions ______________________
  - network performance statistics ______________________
  - information provided ______________________
  - route choice ______________________
  - response to guidance ______________________

- What biases if any, have you identified in the drivers' responses to the simulator?

7. General

- What are the advantages of your simulator?

- What are the disadvantages of your simulator?

- What general problems do you foresee in using simulators for collecting data on driver behavior in the presence of information?

- How can data acquired from operational tests enhance the design of your simulator and the analysis of the simulator collected data?

- If you plan to further develop your simulator, which modifications do you plan to implement and why?