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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

A Systematic Evaluation of the Impacts of Real-Time Traffic Condition Information on Traffic Flow

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EXECUTIVE SUMMARY

The focus of this research effort is the study of driver behavior in the presence of real-time traffic condition information. Advanced Traveler Information Systems (ATIS) are new technologies that will create real-time communication links between drivers and system operators. It has been contended that provision of real-time traffic condition information can improve network performance and relieve traffic flow congestion by assisting drivers in selecting more efficient pre-trip route choices and enroute travel patterns adjustments. With various visual and audible ATIS technologies placed both in-vehicle and at road-side, drivers will be able to receive real-time route guidance and traffic condition information.

Improvements in network performance rely on both short and long-term modifications in driver behavior. The efficiency of travel networks may be increased if significant numbers of drivers adopt more optimal route choices. It is expected that ATIS can help many drivers improve their perception of travel conditions and route choice options. It is therefore critical that ATIS achieves maximum system integration with those drivers who would most benefit from acquiring real-time information and those who are more willing to use these systems.

Even under widespread implementation of ATIS technologies, many drivers will not make good use of these systems. The choice to acquire and use information is dependent on many factors. Therefore, to gain maximum benefit from ATIS, it is necessary to better understand driver behavior under the presence of ATIS. Among the issues that impact drivers' decisions to acquire and use real-time information are the content and format of presentation, an individual's behavioral tendencies and cognitive abilities, and the expected benefits to be gained by using ATIS.

The methodology adapted for this research effort involves three parts: development of a theoretical model for driver behavior under ATIS, interactive simulation experiments, data analysis and behavioral modeling.

The theoretical framework is based on conflict assessment and resolution theories and describes changes in enroute behavior as a response to drivers' perceived inability to achieve travel objectives. Conflict is modeled as a latent theoretical concept that describes increased frustration and anxiety experienced by drivers when expected conditions are deteriorating and the desired travel objectives may not be achieved. Motivation to decrease conflict provides the impetus for drivers to adapt enroute behavior by diverting, acquiring additional information, or revising the travel objectives

Central to the formulation are three basic suppositions: (1) drivers are goal directed and changes in behavior occur as a direct result of drivers' inability to achieve travel goals, (2) drivers' **enroute** behavior is directly affected by perceived travel conditions, individual behavioral tendencies, and specified travel objectives, and (3) diversion and information acquisition are responses to increased conflict arousal and motivation to adapt behavior.

Information acquisition is treated as a response to uncertainty and limited information. Popular theories of human behavior suggest that individuals seek to acquire information from external sources when current perception and memory are insufficient for prediction or evaluation purposes. Information helps decision makers to envision the extent of the conflict. Information is also useful for identifying solutions that were not realized. Generally, it is believed that the more familiar a decision maker is with a problem domain, the less the need is for information. Based on these concepts, it is hypothesized that **ATIS** will best benefit drivers by improving their perception of travel conditions and assisting with route choice decisions.

To facilitate data collection, interactive simulation is used. It is contended here that **in-laboratory** experimentation with interactive simulation can provide a novel approach to data collection and driver behavior analyses. Interactive simulation is a powerful tool for conducting stated preference studies, especially with regard to route choice. The role of a good simulator is to recreate real-world scenarios and elicit from participants responses that are similar to those expected under real-world conditions. This ability to model choice is based on (1) the manner in which a simulator can effectively translate the real world situation to the simulation environment (2) the manner by which physical elements of the real world that play an active role in the choice process are represented. In considering route choice and travel decisions, simulation can be a productive method to isolate choice components and obtain subjective estimations of choice factors.

Limited real-world implementation of Advanced Traveler Information Systems (**ATIS**) technologies has made it difficult to analyze the potential impact on driver behavior. The main reason for using computer-based interactive simulation rather than field studies to model driver choice under **ATIS** is that there have been relatively few advanced information technology systems implemented in the real-world. It would therefore seem difficult for drivers to answer hypothetical questions about technologies they have not yet experienced. Alternatively, interactive simulation provides the opportunity to study revealed behavior by simulating advanced technologies within a controlled environment. With faster and more powerful personal computers, it is now possible to recreate or emulate **ATIS** technologies **in-laboratory** and model driver choice with simulation.

FASTCARS is an interactive computer-based simulator that has been developed for **in-laboratory** experimentation to gather data for estimating and calibrating predictive models of driver behavior under conditions of real-time information. The simulation integrates a model of multiobjective goal specification and evaluation, a real or hypothetical traffic network, simulated real-time information technologies, and interactive driver travel

choices. FASTCARS, designed to model **enroute** travel decision making, provides an artificial environment that replicates spatial and temporal situations that arouse conflict and motivation during travel. The combined effects of perception, conveyed through visual representation of traffic conditions, and prediction, through real-time information availability, form the background choice domain. A scoring and evaluation format, based on weighted additive utility models, provides a basis for analyzing behavior and preference. The purpose is not to study the actual driving process, but rather to focus on the decision-making aspects of travel, including goal specification, route choice, diversion, and information search.

The advantages of using **FASTCARS** over other data collection methods to study driver behavior are realized through the program's flexibility and completeness. The program encompasses the entire driving process from pre-trip planning through arrival at the destination. Players are required to make a broad range of choices including goal specification, route and lane changes, and whether or not to use available information technologies. Furthermore, many system variables, such as network conditions and information content, can be altered to represent different driving conditions. These features allow **FASTCARS** to replicate and model many of the pre-trip and **enroute** decisions common to the trip-making process.

There are several network-specific decisions that must be made in **FASTCARS** pre-trip planning stage: destination, departure time, and initial route choice. The former two choices are actual inputs to the **FASTCARS** program, the latter is reflected by a player's selected route to be traversed. Destination and departure time choices can be selected by, or alternatively predetermined for, the player. The final pre-trip choice to be made consists of specifying travel objectives for the trip. Real-time decisions are made with respect to the perception of goal attainment; during post-trip evaluation drivers focus on how successful they were in meeting their goals. Correspondingly, goal specification and analysis is a central element of **FASTCARS** and is incorporated into the scoring system to analyze the actions and responses of participants.

It is known that several factors influence route choice including drivers knowledge of alternate routes, specific route attributes, and driver preferences. As such, **FASTCARS** models travel performance and route selection through a multiobjective goal set. Each player is rated according to relative success in maximizing utility over a goal set consisting of live predetermined goals. The five goals that are considered are: (1) arrive at destination 20 minutes early, (2) minimize travel time, (3) minimize number of signals encountered, (4) minimize number of road changes, and (5) minimize trip distance. To capture individual behavioral differences and preferences among players, each player is permitted to assign a set of subjective weights totaling 100 to the goal set. At the end of the program, each goal is scored from 0 (worst) to 100 (best) based on the player's ability to achieve these goals. With 100 points in goal weights and a maximum achievement value of 100 per goal, the maximum possible score a player can receive is 10,000 points.

Once the initial route has been selected and the goal set established, the travel sequence begins. **FASTCARS** models travel on a link-by-link basis, ignoring system-wide traffic and focusing on traffic around the player. Play is conducted on a visual display that has four 'windows': the network viewer, the control panel, road-side information viewer, and the in-vehicle navigator.

The largest section of the display, is the network viewer. Players are provided with a birds eye view of a a one mile stretch of a road section. Cars are displayed as small rectangles moving in lanes. The player's vehicle, or cursor car, is shown as the solid rectangle. At the bottom of the road section, the current road is labeled. Cars move by lane, each lane has a specific speed, and generally, lanes to the left have higher speeds.

Players control two basic car movements, lane changing and road changing. Lane changes are initiated by a single keystroke. The cursor car turns into an arrow indicating direction of desired lane change. After a calculated lane-switch delay that accounts for travel conditions, the cursor is moved to the desired lane.

Road changes are available when the viewer displays a cross street. Available turning movements are indicated by arrows on either end of the cross street. The name of the cross street and turning direction is indicated next to the street. When a driver wants to make a turn, two steps must be followed. First, the driver must move to the correct lane. All turns from freeways are made from the rightmost lane. On surface streets, however, right turns are made from the rightmost lane, left turns from the leftmost lane. Second, the driver indicates the turning direction with a single keystroke. The cross street changes color and the arrow indicator blinks. When the cursor car intersects the cross street, it is guided automatically through the turn. If the cursor car is still in the wrong lane when the cross street is reached, the turn will not be executed.

The cursor car is moved to the next road section when it executes a successful turn, passes an intersection without turning, or when it reaches the halfway point on the display. There are a set of next display markers along the roadway to inform drivers when the display will be reset. Surface streets are distinguishable by traffic signals and generally lower speeds. Signals have set timings and on the red cycle, cars caught behind the stop line will queue and wait for the green cycle.

The control panel displays important system information. At the top of the display are the current simulation time and cursor car speed. Below that, the set of five goals are listed. To the left of each goal is the player's selected goal weights; to the right is the accumulated score for each goal weight. These scores will be normalized at the end of the program to values between 0 and 100.

The other two windows are used to broadcast **ATIS** information. **FASTCARS** is equipped to emulate three types of advanced traveler information systems: variable message signs (VMS), highway advisory radio (HAR), and in-vehicle shortest time

navigation system (IVNS). These were selected on the basis of their diversity of presentation and message content.

In the simulation, variable message signs are displayed at certain freeway locations to provide drivers with brief reports on the local traffic conditions on the current link. At points where messages are selected to be displayed, the program searches several miles ahead on the current freeway to gather data on the traffic conditions. Based on the downstream condition, there are four possible message categories to be displayed: "Freeway Clear", "Minor Freeway Congestion", "Major Freeway Congestion", "Incident Ahead". The program uses simple heuristics to decide which message is to be displayed and then posts each message in the upper left-hand window on the visual display.

Highway Advisory Radio is the second information technology simulated. **FASTCARS** utilizes a Voice Adapter which allows players to activate pre-recorded radio messages containing relevant information on highway conditions and on the availability and accessibility of alternate routes. In the current version of **FASTCARS**, incident probabilities and speed distributions are assigned to network links. Before beginning data collection, a series of network profiles that distribute incidents on the network may be generated. Based on these network files, HAR files can also be prepared. At the start of the game, the simulator randomly selects a network profile and set of HAR files to be used.

In-vehicle navigation systems offer drivers a direct source for finding the shortest path to their destination. Through a computerized system, IVNS typically gathers real-time information and instructs the driver where to turn. With IVNS, drivers do not receive traffic information nor do they have to make any predictions or calculations - they merely follow directions. **The benefit** of IVNS is that drivers who are unfamiliar with the network can adhere to the advice and take a shorter time path to the destination. It does not, however, relate explicit traffic conditions; the best path may still be along a congested corridor.

FASTCARS emulates IVNS with a prototype in-vehicle navigator that gathers travel time information. The navigator is displayed in the top right corner of the visual display. When a new link is entered, **FASTCARS** calculates the shortest time path to the destination. This information is used to display in-vehicle navigation information. While activated, the navigator displays three pieces of guidance information based on the calculated shortest path: (1) suggested action for next intersection or freeway exit, (2) expected shortest travel time to the destination, and (3) distance from the current location to the destination via shortest time path.

Using **FASTCARS**, a case study to examine special event traffic was conducted and several modeling techniques were used to systematically evaluate **enroute** behavior and the potential impacts of **ATIS**. A variety of analysis approaches were used to study the data. Category analyses were used to find relationships among variables. Discrete choice

models were employed to estimate primary and secondary diversion behavior. Utility analysis was used to study the potential value of IVNS information acquisition.

A major thrust of the research effort was to analyze the relationship between drivers' familiarity and experience with network layout and travel conditions to diversion and information acquisition propensity. To control for background familiarity, the case study was performed on a hypothetical travel network. Player familiarity was controlled for by the creation of three hypothetical background experience profiles : 'novice', 'intermediate', and 'expert', referred to as 'userlevels' in the experiment. Based on the network layout, a series of graphical displays were developed for each player profile to represent the player's background experience level. Maps for each profile varied in the level of detail provided. Maps for novice players had limited information and revealed a partial set of the freeway system and distances between intersections. Intermediate players were provided with layout and distance information of the entire freeway system and a few major arterials. In addition, a map of freeway speed distributions was also provided. Maps for expert players were designed to reveal the entire freeway and surface street system and also contained speed and incident-related information. The profile maps were available to players at the start of the pre-trip planning phase and throughout the **enroute** travel process.

The series of analyses revealed the following:

1. Driver familiarity and experience with network conditions on primary routes and alternative paths are key indicators of conflict arousal and **enroute** behavior adjustment. It was found that drivers with lower userlevels were more likely to seek additional information.
2. Drivers with lower userlevels also had more diversions per trip. These drivers were more likely to select less efficient initial routes and have lower thresholds of conflict because of their inexperience. These drivers were more apt to divert at medium speeds between 30-45 m.p.h. without sign of major congestion ahead. Drivers with more experience had fewer diversions per trip and higher thresholds of tolerance. These drivers would be more likely to maintain the current route under medium speeds unless other signs of worsening travel conditions were presented (e.g., VMS message).
3. Distance from the destination increased the propensity of drivers to consider alternate routes under adverse conditions. Drivers were more likely to divert or seek information further from the destination.
4. Players with higher userlevels were better able to set and meet their travel goals and generally scored better than their counterparts with lower userlevels. Over 73 percent of 'expert' players scored at least 7500 and 4 percent scored below 5000. This is compared with only 52 percent of 'novice' players scoring at least 7500 and 33 percent scoring below 5000.

CHAPTER 1

OVERVIEW OF REPORT

1.1 Statement of Purpose

Rapid advancement in the development and implementation of Intelligent Vehicle-Highway Systems (IVHS), including Advanced Traveler Information Systems (ATIS) has intensified the need to develop better theoretical formulations and data collection techniques to model dynamic driver behavioral choice. The availability, format, and content of real-time information systems will have a significant impact on driving behavior in the future. Progressive activities in predicting and investigating the evolution of information-aided driving behavior will assist efforts in research and development of these new technologies.

This report proposes both a new theoretical framework and an innovative data collection approach to analyze the complex relationships comprising static and dynamic enroute driver behavioral choice. The conceptual development is based on theories of conflict arousal and motivation previously applied in other disciplines, including psychology and consumer behavior, to model behavioral choice. Central to the formulation are two basic suppositions: (1) drivers strive to meet a set of travel goals and (2) changes in enroute behavior occur from drivers' perceived inability to achieve travel goals. The value of acquiring real-time information is incorporated into this theory as a factor that contributes to drivers' perception of travel conditions and knowledge of network patterns and characteristics.

Modeling driver behavior through conflict arousal and resolution provides a basis for examining both the dynamics of driver choice and the advantages of ATIS technologies to influence choice. Temporal changes in driver behavior are explained by driver familiarity and experience, aided by real-time information acquisition. In the short term, travel decisions are contemplated for estimating and improving the perceived certainty of meeting prescribed travel objectives. Long-term modifications in travel behavior patterns evolve over time from learning and experience.

The proposed modeling approach differs from most traditional choice models applied to travel demand, such as static mode or route choice, which suggest that drivers attempt to select the best alternative from a set of alternatives. Rather, it is asserted that the initial route choice, selected during pre-trip planning, is itself a static choice. Once enroute, changes from initial travel plans result from a two stage process of assessment and resolution. As perceived or anticipated travel conditions worsen, the probability of goal attainment decreases and the desire to modify behavior increases. Drivers' perception and anticipation of travel conditions reflect the certainty of goal attainment and the desirability of continuing on the initial path. As the current path becomes less desirable, jointly impacted by worsening of travel conditions on this path and the awareness that alternate

paths with potentially better travel conditions, the likelihood that drivers will modify their behavior increases. Resolution of the situation, through diversion or changing of the goal set, is a complex choice influenced by the perception of travel conditions on the current and alternate paths, the goal set, and individual behavioral tendencies.

Data collection is accomplished with the help of FASTCARS, Freeway and Arterial Street Traffic Conflict Arousal and Resolution Simulator, an interactive computer-based simulator designed to model spatial and temporal effects of driving and emulate real-time information exposure, search, and acquisition. **FASTCARS** allows for controlled experimentation to identify and measure various factors which impact trip-making and driver behavior. With interactive simulation it is possible to directly observe drivers' reactions to changing network conditions and real-time information acquisition.

1.2 Background

Traffic congestion is compounded directly or indirectly by inefficient route choice and travel planning. The need for drivers to make better travel choice decisions has become more critical as the number of cars competing for available road space increases. It is expected that demand on America's roadways will double by the year 2020 (USDOT, 1990). Increasing capacity through the construction of new highways will continue in rural and outlying suburban areas where land is available and congestion is still manageable. In urban centers, where the cost of construction and acquisition of new rights-of-way is extremely high, it is less practical to increase capacity via new construction. Brand (1988) stated that the issue of whether to build more freeways is "not even a serious question in most urban areas."

One approach to the congestion and capacity problem is to improve driver awareness of real-time network conditions to induce short and long-term changes in travel behavior. Some experts believe that on a day-to-day basis route diversion, in response to incidents, special events, or other non-recurrent temporary blockages, has a great impact on improving system performance. Over the long run, redistribution of traffic demand, through changes in route choice and departure time, may help to increase network efficiency.

Recent research efforts aimed at facilitating the need to provide drivers with real-time information, have focused on developing Advanced Traveler Information Systems (ATIS) capable of distributing real-time data to motorists. These technologies, including highway advisory radio (HAR), variable message signs (VMS), and in-vehicle navigation systems, will enable drivers to receive up-to-the-minute traffic congestion information or route planning assistance. On a daily basis drivers **enroute** will be able to exploit these technologies for diverting around network links which are heavily congested. In the long term, better exposure to network-wide traffic conditions and route choice options should enable drivers to adapt travel patterns in light of non-recurring congestion more efficiently.

To ensure success of **ATIS** development and implementation in the upcoming years, it is important to have a good understanding of driver behavior and the changes that real-time information will evoke. It is clear that availability of real-time information will have a profound effect on drivers' travel choice behavior. Yet, little is known about the direct impact of various information technologies, format of information presentation, and the level of information content on drivers' perceptions and behavior.

The influence of individual behavioral differences and characteristics on driving choice is equally unclear. Although studies have shown that system performance may be enhanced through the introduction of real-time information sources on networks and driving populations, there have been few models developed to define or predict the impacts of real-time information on individual driver choice behavior. These studies were limited to either estimating factors which influence **enroute** choice or describing day-to-day adjustments in pre-trip planning.

1.3 Proposed Research

The modeling approach posed in this study, based on conflict recognition and resolution, explores driver reaction and response to changes in the surrounding transportation system. It is shown that short-term changes adopted by drivers are directly related to a measure of perceived certainty in attaining goals. Conflict recognition arises **enroute** when drivers perceive that they will be unable to attain a set of travel goals. When this conflict becomes too great, drivers must decide whether or not to respond by changing their current travel behavior. In considering route diversion, drivers weigh the comfort of maintaining the current path but possibly failing to achieve the desired state against trying to improve their certainty by moving to alternate paths. Perception and information play a key role in measuring levels of certainty and perceived risk experienced by drivers engrossed in possible route diversion choice sets.

The motivation behind this project is to advance the state of research on predicting driver choice behavior and analyzing the impact of perception and information on decision recognition and response. This will be accomplished through three phases: (1) development of a theoretical formulation which explicitly treats interactions between **pre-trip** planning, **enroute**-adjustment, and **post-trip** evaluation, (2) implementation of an interactive computer-based data collection tool based on the theory, (3) estimation of a behavioral choice model from a case study using data collected via the computer simulation.

Central to this approach is quantifying the short and long-term impacts of real-time information exposure on individual drivers. Emphasis is placed on classifying an individual driver's behavior by preferences and attributes, estimating driver decision protocols under various levels of real-time information, and explaining factors which preclude and induce route diversion and dynamic evolution of travel behavior patterns. The operational analysis will be directed to the following tasks:

- (1) Defining a conflict model of individual driver choice to explain real-time **enroute** assessment and adjustment.
- (2) Estimating levels of personal threshold to conflict as a function of experience, goal striving, risk behavior, and other behavioral differences.
- (3) Describing how cognition, determined through prior experience, current perception, and information acquisition, impacts **enroute** perception and choice to stimulate conflict arousal and response.

The formulation of the conflict model will be based on previous efforts in studying conflict assessment and information acquisition rooted in psychology, consumer behavior, and behavioral decision theory. Prior research in travel behavior, consumer behavior, psychology, and behavior analysis have shown that choice is initiated through conflict recognition. Furthermore, the ability to make optimal decisions is a function of the extent to which humans undertake information search and acquisition (Hogarth, 1990). In reaction to conflict situations, decision makers draw from prior experience, current perception, and if necessary, seek to acquire additional information to assist in the choice process. The initiative to acquire information and the subsequent activity of interpreting and incorporating information into choice help to assess the perceived severity of conflict, the perceived certainty and risk associated with achieving goals, and the ability of the decision maker to respond. In this study, special attention is given to the relationships between (1) perception and information with predicting certainty and risk, (2) stimulating need recognition and motivational response, and (3) goal definition, route loyalty, and disposition to route diversion.

Real-time information can improve the ability of drivers to quantify congestion, measure delays, and anticipate travel conditions on alternate routes - all factors which influence route assessment and diversion decision making. The influence of real-time information on drivers is explored as part of the theory of conflict arousal and resolution under conditions of perfect information. Issues of driver confidence and trust toward **ATIS** information, although important, was deemed secondary to the direct issues of driver decision making being explored here.

Simulation is a powerful tool for studying real-time decision making and modeling intricate systems. **FASTCARS** was developed to enable controlled study of travel behavior and real-time information acquisition under theories of conflict assessment and resolution. A case study involving special event travel was performed to showcase the advantages of using simulation for data collection. The data resulting from this study was used to systematically evaluate **enroute** driver behavior and the potential impacts of **ATIS**.

1.4 Research Hypotheses

Little is known about the direct impact of various information technologies, format of information presentation, and the level of information content on drivers' perceptions and behavior. Moreover, the influence of individual behavioral differences and characteristics on driving choice is equally unclear. Although studies have shown that system performance may be enhanced through the introduction of real-time information sources on networks and driving populations (Mahmassani and Jayakrishnan, 1990; Arnott et al., 1990), there have been few models developed to define or predict the impacts of real-time information on individual driver choice behavior.

This research approach is based on a few simple hypotheses that are used to form the theoretical formulation and provide the basis for the computer simulation and the case study. The general behavioral approach presumes that drivers tend to follow an established travel plan until conflict increases and exceeds some threshold of tolerance. Only when under significant duress are drivers aroused to consider changing the current trip plan. The decision to change is based on the severity of perceived conflict and the availability and accessibility of alternative strategies. To implement change, there must be some significant improvement in perceived attractiveness of moving to an alternative choice set.

The approach used to develop this conflict model of driving choice in the presence of real-time information on trip making is constructed through several theories intended to define the focus of the study and provide a methodology for testing and evaluating the model. There is a basic set of hypotheses that form the framework for the modeling approach corresponding to the driving process, assessing conflict, and information acquisition and processing.

The driving process analyzes drivers, trip choice, and objectives of travel. It is assumed that trip making is divided into two headings, familiar and unfamiliar. Drivers familiar with networks generally select a trip plan based on prior experiences; unfamiliar drivers use different means to plan travel.

The model expects different reactions from each type of driver. Drivers who are familiar are more likely to recognize conflict but less likely to seek information and more likely to change. Familiarity should also impact diversion behavior. Less familiar drivers should be less willing to divert onto a surface street.

Conflict is modeled as an index which measures behavioral instabilities which could lead to reaction. It is influenced by many factors including: perceived and predicted delay in travel, traffic conditions, uncertainty of route choice, rigidity of starting or arrival time, trip type, and other utilities of travel. Conflict is hypothesized to be initiated in two ways. Perceived conflict is self-generated by drivers in response to their perception of network conditions. Acquired Conflict is externally stimulated by acquisition of real-time

information. Threshold of conflict tolerance is assumed to be based on individual driving behavior and dependent on spatial and temporal factors.

Real-time information assists drivers to perceive network conditions and the availability of alternative strategies. Drivers are expected to seek information either before experiencing much conflict or in response to severe conflict. In the former case, during trip making, even **before** signs of conflict, drivers may monitor information to receive advanced warning of conflict. Once in conflict, drivers seek information to gain extra knowledge about traffic conditions or for information on alternate routes. In either case, information acquisition is dependent on the severity of conflict and the complexity of the problem. The search process begins when drivers **feel** that they are unable to handle the situation only with current perception and past experience.

1.5 Research Approach

The development of the conflict model and subsequent analyses serve to answer many questions concerning driver behavioral choice and real-time information acquisition and processing. Estimation of the model is based on several hypotheses on drivers' ability to assess and tendency to react to conflict and choice situations. The modeling methodology is developed as a hierarchical structure representing the various levels in the relationship between driver behavior, travel choice, conflict, and information acquisition. The three level structure casts trip choices as a special component of decision making which in turn is a function of cognitive processing. Each stage of travel choice can be individually modeled as a decision point and defined by the morphology of defining problems, evaluating solution sets, and implementing choice. Similarly, each phase of decision making is influenced 'by human perception and response as a function of cognitive processing.

This approach isolates key elements of driver decision making to analyze the joint effect of individual behavior, perceived conflict arousal, and information acquisition. It is shown that assessment and prediction, as well as evaluation and choice, are functions of individual behavior, perception, memory and experience, and external stimulation.

The need for real-time information to assist in assessing the extent of conflict or evaluating choices in response to conflict is drawn out in the model. The model specification allows for a wide range of testing combinations to determine what behavioral factors, trip types, network conditions, and sources of information impact drivers' choice, perception of conflict, and threshold of conflict tolerance.

1.6 Research Contributions

This report provides several research contributions to the current state of research. Over the past few years there have been several research projects focusing on dynamic driver

behavior, **enroute** diversion, and impacts of real-time information **acquisition**. This project adds new variations to this area.

The theoretical formulation presented and tested in this effort expands the currently accepted conceptual framework for **enroute** diversion. Various researchers (i.e., Ben-Akiva et al., 1992) have posed that driving is a goal oriented process. Similarly, it has been theorized that diversion occurs when thresholds of expectations have been breached (i.e., Khattak et al., 1991). The theoretical formulation to be presented in this work forms a complete framework for behavioral choice **firmly** rooted in well documented theories of human behavior applied in other disciplines including psychology and consumer behavior. The proposed modeling approach, coined here as 'conflict arousal and response' was adapted to help systematically examine **enroute** driver choice and better understand real-time information acquisition.

A major portion of the proposed theory for diversion involves behavioral decision theory under risk and uncertainty. The ability to classify driver behavior and estimate how uncertainty and risk are factored into route decisions and information acquisition is important in the context of travel choice. It is clear that perceived travel conditions differ from actual conditions and has a major influence on driver behavior.

Unlike previous studies of driver behavior that relied on stated or revealed preference survey, data collection and analyses was performed in-laboratory with a special microcomputer-based interactive simulator developed to model driver decision making and emulate **ATIS**. Interactive computer simulation is rapidly becoming a serious alternative for data collection to rival survey and field studies. An effective system for collecting and analyzing driver behavioral choice data is essential to any project. Previously, the lack of suitable real-world implementation of real-time information technologies has restricted the study of driving behavior. Most previous research on route or point diversion and the influence of real-time information has involved stated or revealed preference studies of commuters or special event attendance. It is believed that while gathering observed behavior is still out of the reach of most researchers, laboratory experimentation, through simulation, will provide a better source of data. Advanced computer-based simulation will lend itself to the study the complex process of human behavioral choice influenced by the direct interaction with real-time information technologies.

This study also advances the state of current research by directly examining the impacts of various **ATIS** technologies. **FASTCARS** emulates Variable Message Signs, Highway Advisory Radio, and In-Vehicle-Navigation Systems, and from this it is possible to test driver attitudes toward using these technologies and to what degree these technologies may influence **enroute** diversion behavior.

Finally, in the areas of demand forecasting and travel behavior, this project provides an **in**-depth analysis of both static and dynamic driver choice and projects drivers as behavioral actors. Previous models of travel demand have probed the static choice process of

selecting routes, departure times, or other components of travel. Conversely, this project aims to examine dynamic reaction and choice. This research also provides an in-depth look at behavior and choice to depict drivers as multidimensional decision makers. Cognitive processing, information acquisition, and behavioral decision theory are joined to provide a better model of driver behavioral choice.

1.7 Organization of Report

This report is composed of three major parts. The first section highlights past research efforts and details the proposed theoretical formulation and data collection process. Chapter two provides a full literature review on several related areas. The review begins by analyzing the current research on the relationship between real-time information, driver behavior, and system performance. These are critiqued in the context of defining and solving the overall problem domain. The chapter then turns to discussing decision making and individual choice theory. The contribution of psychology, economics, and transportation to research on behavior, choice, and utility is reviewed. These findings serve as the basis for this study.

Chapter three formulates a conflict model of driving behavior and travel choice. This chapter details the hypotheses and theories used to develop the formulation as well as presenting a mathematical interpretation of the theoretical formulation. The relationships between component parts are promoted and a set of measurable and controllable variables are suggested. Chapter four discusses the development of **FASTCARS** and how this computer-based simulator is used to test the theoretical formulation and hypotheses presented in chapter three. Included in this model will be a discussion of the general choice process, the role of pre-trip planning and **enroute** choice in travel, and an analysis of how uncertainty impacts travel decision making.

The second part of the report presents the data collection, analysis and experimental results. Chapter five details the case study and describes the data collection process. Chapter six discusses how the data was analyzed and provides a summary of the results. Last, chapter seven, presents the conclusions and recommendations stemming from this research effort concluding with a summary of major findings.

CHAPTER 2

REVIEW OF PERTINENT LITERATURE

2.1 Introduction

This research effort involves a diverse collection of theories and approaches. This chapter is intended to provide the reader with a basic level of understanding of these concepts as well as a general historical overview of recent research efforts that have influenced this project. When appropriate, the discussion will serve to critique prior efforts and highlight obvious voids that the proposed research effort aims to address. As such, the historical review encompasses the following topics:

- (1) Emergence of Advanced Traveler Information Systems as a means to alleviate congestion and improve network performance.
- (2) Traditional approaches for modeling driver behavioral.
- (3) Applying conflict theory and extensions developed in psychology and consumer behavior to model driver choice and information acquisition.
- (4) Using interactive computer-based simulation for data collection and analysis.

As a prelude to the discussion, the chapter begins with some general observations and perspectives on the problem domain. The chapter ends with an overview of the proposed research approach, beginning to address the issues raised.

2.2 Perspectives on the Problem Domain

Driver behavioral choice is a complex process influenced by many factors. Renewed efforts to develop better modeling methodologies have emerged over the past few years necessitated by development of ATIS. To understand how ATIS technologies will impact system performance on a macroscopic level, research has focused on estimating to what degree individual driver's behavior will or can be adapted through information exposure. Unfortunately, it is difficult to specify a single model or theory which encapsulates all of the necessary components for analyzing driver behavior. The combination of external stimuli with individual behavioral and psychological differences lead to a complex decision making process. In addition, the heterogeneity which characterizes this problem area is also evident in a multitude of research efforts from diverse disciplines which have attempted to analyze other types of human behavioral choice, such as consumer behavior.

The exigency to further the study of driver behavior has been motivated by increased research activity in the development and implementation of Intelligent Vehicle Highway

Systems and Advanced Traveler Information Systems. Therefore, as a prelude to discussing the theories and research associated with this project, it is necessary to review the historical progression of research which has shaped the current effort.

Few transportation models are able to fully capture the complexities of driver behavior, explain what factors influence driving choice, and reveal drivers' success in meeting their objectives, notwithstanding the need to include the impacts of real-time information. There are several reasons for the general lack of significant progress in this area (Mahmassani and Jayakrishnan, 1990; Ben-Akiva et al., 1990).

- (1) Many observations and extensive data collection are needed to develop comprehensive models of behavior. Driving involves a very large choice set and an even greater number of possible reasons for making judgments; estimation is therefore rather expensive and difficult.
- (2) Recent interest in modeling response to real-time information has motivated more in-depth study of driver behavior. Traffic simulation programs generally do not invoke behavioral models for determining flow patterns. Network equilibrium assignment models are used for planning, not traffic operations, so they also generally do not rely on behavioral models.
- (3) When behavioral models are needed for traffic assignment, simplified models of driver behavior based on assumptions of shortest path and minimum travel times and delays are usually employed.
- (4) Most prior efforts on traveler information systems have been concerned with technological aspects and human factors for deployment purposes. There has been limited attempt to quantify the impact of these information systems on driver behavior or system performance.

In the past decade there has been a growth of research to produce more complete models of driver behavior. The urgency to incorporate effects of real-time information into a modeling scheme has added further complexity to the approach. The problems have been compounded by the inability to generate adequate data to study the impacts of information on driver choice since most **ATIS** technologies have yet to be implemented. Mahmassani and Jayakrishnan (1990), based on their research on system performance and user response under real-time information, summarize many of the problems inherent in research related to modeling behavioral choice:

“It is natural to question the above model of path switching in response to real-time information. In the absence of extensive observational evidence, which is rather difficult to obtain when the technology being evaluated is not quite in place yet, no claim can be made that any one model of behavior provides the only possible representation of reality. . . . After all, one would not want to predicate major investment decisions on results that cannot be shown to be robust with respect to the underlying behavioral assumptions.”

The general consensus suggests that an overall framework to studying this problem domain must include models of system performance, driver behavior, driver decision making, and information search and acquisition. Moreover, these models, at a minimum, must be able to handle temporal and spatial considerations of traffic flow, account for relationships of driver perception, memory, and experience, focus on all levels of trip making including pre-trip planning and **enroute** assessment and adjustment, and deal with response to diverse information system technologies and message formats and contents.

2.3 Emergence of Advanced Traveller Information Systems

The recent emergence of IVHS technologies has initiated a new wave of approaches to quantifying the potential impacts of real-time information on driver behavior and network performance. Yet, research and development of driver information systems dates back almost three decades. Earlier research in driver information technologies, started in the sixties, evolved as part of greater efforts in creating urban traffic surveillance and control systems. Much of this early work has influenced today's approaches. Still, the goals have remained the same throughout the years: better management of traffic flow, enhanced driving operations, and improvement in driving safety.

The historical evolution of research and development of information technologies is important for recognizing the current emphasis on driver behavior modeling. Therefore, the following sections are devoted to reviewing significant contributions in this field over the past twenty-five years. The first section begins by discussing current world-wide activities in IVHS research over the past decade. The second section provides an overview of the early years of research in the areas of traffic surveillance and information systems.

2.3.1 Recent IVHS Research

Recent activity in research related to analyzing driver behavior and the impact of real-time information has largely been a direct result of the growing interest in Intelligent **Vehicle-Highway Systems**. IVHS are generally conceded to be the next generation in traffic control in America and around the world. As highway travel continues to be the dominant mode, traffic volume is expected to double over the next thirty years. As more travelers jam the highways, it is expected that large economic losses will be incurred on account of increased accidents. Moreover, the financial burden to construct new highways and the ever increasing environmental impacts have added to the stresses of highway travel. It is agreed world-wide that newer approaches must be developed to improve system performance, improve travel safety, and decrease environmental impacts (Willis 1989; Office of Economics - USDOT, 1990).

Advanced Traveler Information Systems are one of the major components of IVHS activities. Worldwide research on **ATIS** has centered around the development and implementation of several visual and audio technologies for route guidance and vehicle navigation. Historical overviews of automobile navigation technology and reviews of cooperative efforts around the world in producing advanced route guidance systems have been provided by French (1986, 1989). The main objective for developing **ATIS** technologies is to improve driver route choice efficiency by assisting in pre-trip planning and **enroute** navigation. This is accomplished through providing real-time information on network conditions (e.g., links affected by congestion, weather, and other factors) and better travel paths. **ATIS** technologies being developed include on-board navigation systems, pre-trip route planning systems, traffic information broadcasting, and electronic route-guidance systems.

In the United States of America, federal and local involvement in IVHS research dates back to the mid 1980's. Since that time, programs such as IVHS America, the California Partners for Advanced Transit and Highways (PATH) and MOBILITY 2000 have begun to formulate general plans for IVHS research (Mobility 2000, 1989). Other current major research investments in America at the state or private industry level are focused primarily on driver information systems. These independent efforts include General Motor's **TravTek** Project (Rillings, 1991), and the Chicago Dynamic Route Guidance System (Boyce et al., 1991).

Costs of research world wide are estimated to run in the billions of dollars. Federal Highway Deputy Administrator Eugene R. McCormick stated in his address at the Transportation Research Board 71'st annual meeting that "The Federal Year 1991 Federal Program delivered over \$23 million in research and development, program support, and operational test project obligations." Through the IVHS Act of 1991, this total of government expenditures is to rise throughout the decade. Saxton and Bridges (1991) predict that there will be significant benefits from improved mobility, safety, energy savings, and air quality. Although further analyses of benefits are needed, it seems possible that there is great potential in advanced technologies (Mobility 2000, 1990).

Likewise, foreign governments are spending billions of dollars on IVHS research. They too agree that a substantial return may be gained from their research dollars and preliminary reports substantiate these claims. Kobayashi (1979) and Tsuji et al. (1985) estimated that in-vehicle route guidance systems being developed in Japan will reduce travel times by six to fifteen percent. Jeffery (1987) commenting on the European research on these technologies also concluded that implementation will result in substantial time savings for drivers.

In Europe, 1 billion dollars has been allocated for IVHS as part of EUREKA, a cooperative effort between 19 countries to develop advanced technologies for highways. (USDOT, 1990). Among these programs is "Program for European Traffic with High Efficiency and Unprecedented Safety"(PROMETHEUS) (Gullstrand, 1987; Karlsson, 1988), and CARMINAT.

2.3.2 Previous Activity on Developing Traveler Information Systems

Some of today's **ATIS** technologies such as Highway Advisory Radio (HAR) and Variable Message Signs (VMS) represent improved systems over earlier models. Other systems, such as in-vehicle guidance systems, are entirely new technologies. In either case, improvements in computer and electronic technology have made theories and prototypes of the past twenty years into blossoming realities.

As early as the 1960's, it was known that increased congestion was disrupting travel performance in many of America's major cities. Large metropolitan communities, such as Los Angeles, Detroit, and Chicago, began projects to research, develop, and test advanced technologies for traffic surveillance and real-time information dissemination (Baker, 1964; West, 1969). It was believed that with the advancement of more powerful computers and other technologies, a centralized coordination of highway systems through real-time traffic surveillance and control strategies would be useful to improve operations.

By the 1970's several traffic surveillance and control projects were in full implementation around the country and the world. Details of the experimental effort in Los Angeles are described by the California Business and Transportation Agency (1971). Detroit developed an information and traffic control system for their John C. Lodge Freeway (Pretty et al., 1971). Carlson and Benke (1973a, 1973b) document the freeway surveillance and control system implemented on major interstates in Minnesota. McDermott (1974) reviewed progress on Incident Surveillance and control for the Chicago area. Similar projects were undertaken internationally in cities like Toronto (Hewton, 1975) and Naples (Nenzi and Anglisant, 1974).

Driver information systems have always been viewed as an integral part of traffic surveillance and control. In each of the examples cited above, driver information systems, including audio, visual, or combination components, were implemented as part of the projects with the goal being to coordinate driver information in connection with surveillance to assist drivers in avoiding major congestion areas and informing them of alternative routes. The efforts in Los Angeles to develop traffic control systems underscored the need to combine surveillance and driver information. For example, Puncke (1968) addressed the issue of motorists and information during a speech before the Institute of Traffic Engineers in Los Angeles. He stressed that drivers' ability to understand signs, especially during heavy congestion, are a key for managing traffic coordination and control. As a result of the concern for driver information, a major part of the Los Angeles project was to test warning and information systems implemented through radio and changeable message signs (West, 1969).

2.3.3 Message Signs : Visual Aids

Providing drivers with information through visual aids has long been the standard. Traffic lights, road-side signs, and other visual displays have been used to direct traffic. As such, much of the early work in the 1960's was focused on using visual displays to provide route guidance and diversion information (for examples see Dudek, 1962; Clinton, 1963; Gervais, 1966; Wattleworth et al., 1969). In the 1970's there were many human factors studies undertaken to help improve the design of visual displays by studying how drivers react to message signs. Several of these studies focused on designing visual systems for urban highways to provide real-time traffic information as well as diversion information at key intersections and ramps (Dudek, 1970; Pretty and Cleveland, 1970; Dudek et al., 1971). Other research efforts focused on the physical issues associated with construction and deployment (Case et al., 1971; Allen and Lunenfeld, 1971). The Highway Research Board, in response to the growing interest in this field, published two special reports (No. 129 in 1971 and No. 147 in 1973) which were dedicated to designing and using changeable messages for traffic control. International interest in message signs were also heightened at this time. Hodge and Rutley (1974) describe research done in Britain on the evaluation of various changeable message signs. The Federal Ministry of Transport in West Germany (1975) described their country's study of control models for traffic control and variable message signs. Dorsey (1977) prepared a special report for FHWA on variable message signs and traffic control.

From the earliest projects in traffic control, it was seen that information influenced driver behavior and improved network performance. Experiments in Chicago, Los Angeles, and Detroit found that drivers responded to information signs and adapted their short-term route choice (Dudek, 1970; Pretty and Cleveland, 1970). Furthermore, other studies noted important relationships between driver behavior and information presentation. It was found that information consisting of qualitative measures of traffic conditions were preferred by drivers over quantitative delay and speed data (Dudek, 1970; Knapp et al., 1973). Heathington et al., (1970) noted that traffic condition information was more useful to commuters traveling on expressways than for drivers of city streets. Hall and Dickinson (1975) surveyed commuters in the Baltimore area to identify the types of information desired to best assist driving decision making. They found that drivers preferred three types of qualitative messages: (1) length and cause of congestion, (2) diversion instructions, and (3) information on alternative routes.

In the 1980's message sign technology advanced and implementation continued. Young (1986) described the conception, development and construction of a freeway surveillance and traffic control system on Interstate 75 and on Interstate 71 in downtown Cincinnati. Young explained how changeable message signs are used to provide drivers with real-time information on incidents and congestion. Henry and Mehyar describe how Washington state has designed and maintained a traffic control system to improve flow in the Central Puget Sound area. Variable message signs have played an important role in this project.

2.3.4 Highway Radio Systems : Audio Aids

As radio technology improved in the 1950's and radios were becoming standard equipment in automobiles, several projects were undertaken to test the use of audio systems for traffic control. General Motors Research Laboratories conducted several research projects for integrating audio communication into traffic control systems (Quinn, 1959; Hanysz et al., 1960). Weinberg et al., (1966) discuss the effectiveness of using an airborne observer to control traffic. Traffic condition information gathered by the observer would be relayed by radio to drivers.

In the 1970's several highway audio systems were discussed as alternatives or supplements to visual message systems. Carlson and Benke(1973) describe an HAR demonstration project on I-35W in Minnesota. In 1974, Anderson and Roberston completed a study for FHWA that reviewed a complete Highway Advisory Information Radio system in North Carolina, looking at all elements of design with detail on signal strength and location of transmitters and antennae. Today, most cities have one or more HAR systems, typically on major highways or around airports. For example, currently in Southern California, there are several HAR systems in place; several major freeways have their own system and there are special systems around Los Angeles International Airport and Anaheim.

2.3.5 In-Vehicle Interactive Navigation and Communication Systems

Both VMS and HAR technologies are based on an outside observer feeding information to a central processor and in turn, appropriate messages are then posted visually or audibly. The possibilities of two-way communication or interactive systems was first presented in the late 1960's. Early studies in this field focused on emergency response using interactive communication through Citizen Band Radio (CB) (Bauer et al., 1969; Chairamonte and Kreer, 1972; Trabold and Reese, 1974). Today, interactive communication is an integral part of traffic monitoring and ATIS system development. Many highway traffic reports rely on receiving reports from drivers who use their car phones to provide real-time reports on their perceived travel conditions.

Recent IVHS research is focused on developing navigation systems capable of collecting and transmitting location of vehicle location and guidance information. Technologies such as area broadcast systems, mobile radio systems, and local roadside transceiver systems are capable of collecting and distributing vehicle location and navigation information throughout local networks. These systems would require equipping automobiles with special detection technologies that would enable sensors to locate these automobiles and feed data into a central bank to be processed.

Since the 1970's there have been a variety of research efforts undertaken to develop technologies capable of providing drivers with in-vehicle route guidance. The first major project, sponsored by the Federal Highway Administration in 1970, was ERGS (Electronic Route Guidance System). The research was aimed at providing drivers with in-vehicle

directional guidance based on the desired origin-destination trip plan (Rosen et al., 1970). This project was shortly abandoned by the government in 1971. More recent projects include California's PATHFINDER project coordinated between the Federal Highway Administration, General Motors, and the California Department of Transportation (CALTRANS). Vehicles will be equipped with in-vehicle electronic mapping and real-time communication technology. Drivers will be able to directly communicate with a Traffic Operations Center (TOC).

In the mid seventies, Japan began a series of research projects based on the ERGS model. The first effort, CACS (Comprehensive Automobile Traffic Control System) began in the mid 1970's (Fuji, 1986) and was followed in the 1980's by RACS (Shibano et al., 1989) and Advanced Mobile Traffic Information and Communication System (AMTICS) (Nakashita et al. 1988; Okamoto, 1988; Okamoto et al. (1988). European efforts closely followed the Japanese successful research. Current European efforts in IVNS include the German ALI-SCOUT and British AUTOGUIDE (Jeffery et al., 1987, Belcher et al., 1989) projects. Both systems provide in-vehicle directional information gathered from road-side beacons.

2.4 Modeling Driver Behavioral Route Choice Under Information

Travel choice encompasses a variety of trip-related decisions including departure time switching decisions, pre-trip route selection, and enroute adjustment. Recurring and non-recurring congestion together with real-time traffic information acquisition has a profound effect on travel choice. One of the main attractions of providing drivers with real-time information is the potential to reduce individual travel times, delays, and wasted mileage by improving enroute diversion behavior as well as pre-trip departure time-route choice decision making (Boyce 1988).

Early research focused on predicting aggregate route or mode choice patterns based on utility and probabilistic choice models. This was followed by studies on distinct aspects of trip making, such as departure time or route choice. As work progressed, system performance, habitual travel patterns, dynamic and day-to-day adjustments, the impacts of real-time information, and other related issues were slowly addressed and brought to the center of attention. Most recently, efforts have been turned to developing a central theory which encapsulates all of these critical components. The complexity and vastness of this problem area has just begun to be tapped into.

This section of literature review focuses on primarily the last decade of research in driver behavioral choice. The purpose is to develop an overall view of research evolution and lead into the central themes of this thesis. Therefore, the review has been pared to two major headings: (1) departure time and route choice and (2) Enroute diversion behavior. Discussion on the impacts of real-time information on these decision processes are included in each section.

2.4.1 Departure Time and Initial Route Choice

Much of the work on traveler choice has focused on pre-trip behavior, departure time selection and initial route choice. The relationship of departure time and route choice is seen as an integral part of describing and predicting dynamic behavioral choice. As drivers become familiar with traffic patterns on their network, their trip patterns, which fulfill individual goals and objectives with respect to travel times and other considerations, are adapted over time through experimentation and adjustment to departure times and route selection.

It was determined from early on that time savings was one of the most significant factors of route choice decisions (Knapp et al., 1973,). Since commuters made up a majority of peak-trips, when time is of the essence, much of the early analyses focused on commuter departure time - route choice decision making (Abkowitz, 1981; Hendrickson et al., 1981; Hendrickson and Choicer, 1981; de Palma et al., 1983). It was found that commuters were very likely to adapt departure behavior to ensure they would arrive to work on time (Hendrickson and Plank, 1984). Abkowitz (1981) found that these departure time decisions were influenced by perceived route characteristics.

Later studies looked at dynamic aspects of the joint effects of departure time-route choice decisions. Mahmassani and Herman (1984) experimented with commuters under assumptions of minimizing a linear cost function. Abu-Eisheh and Mannering (1987) showed that there is promise for developing continuous models for estimating dynamic route and departure time choices for commuting trips. They extended previous efforts by implementing a logit formulation based on a two part linear utility function. This function described the utility for a given route by two factors described as expected travel time on that route and vector of route characteristics. Ben-Akiva et al. (1990), theorized that the heuristics of enroute decision making are based on a comparison between the utility from previous travel and expected utilities for the new trip. Personal preferences influence choice.

A wave of research at the University of Texas developed more complex models of static and dynamic commuter behavior looking at day-to-day dynamics (Chang et al., 1985; Mahmassani and Chang, 1985 & 1986; Mahmassani et al., 1986). These efforts were based around a theoretical framework that modeled driver behavior as boundedly rational, suggesting that drivers may not optimize, but satistice their choice behavior. There were several key findings **includings**: (1) an indifference band of tolerable schedule delay in conjunction with prior experience impacts commuters' departure choice, (2) under a given demand, users must be willing to accept certain amount of schedule delay as a price for ensuring reliability of on-time arrival, and (3) drivers coming from a more distant location had a wider indifferent band.

Mahmassani and Tong (1986) and Tong et al., (1987) simulated the effect of information availability on user behavior dynamics. It was concluded that commuters combine

information with prior experiences in delay and travel time to form a basis for predicting travel time for future trips. Previously experienced schedule delay influences the prediction of travel times and often leads to an adjustment in departure times for future trips. In addition, additional travel-related information reduces drivers' perceived uncertainty associated with system performance, and clarifies choice sets.

Several studies have found a relationship between departure time and route choice decisions and drivers acquiring available traffic condition information. Hamed and Mannering (1989) modeled equilibrium traffic flow on different roads to compare flow under normal conditions versus flow altered by incidents. They also added an information effect to the system by randomly selecting seventy percent of the commuters to receive perfect information. They found that drivers with perfect information will try to alter route plans to avoid incidents by changing travel time, changing routes, or both.

2.4.2 Enroute Diversion

Enroute diversion has mainly been studied in the context of non-recurrent congestion such as road maintenance and special events (See Khattak et al., 1992 for a full review of stated and revealed survey analyses on diversion behavior). It has been shown that several factors impact drivers' **enroute** assessment of travel performance and subsequent diversion decisions.

Thresholds of tolerance to delay or travel expectations have been shown to be key indicators of drivers' willingness to divert. Huchingson and Dudek (1979) and Huchingson et al., (1984) found that the length of delay in relationship to trip time impacts diversion behavior and that drivers have thresholds of tolerance with respect to delay. More recently, Haselkorn (1989) and Allen et al. (1991) found that there is a great variation among drivers' willingness to divert as a function of delay.

Khattak et al., (1991) theorized that drivers who make regular trips develop expectations of travel time and congestion. When there are large discrepancies between the experienced conditions and the perceived, drivers may be more likely to divert. They contend that thresholds of expectation vary among drivers and for each driver may vary by route and situational factors.

In studies on commuter practices, it has been found that increased delay causes significant numbers of commuters to divert from intended routes (Huchingson et al., 1977; Stephanedes et al., 1988; Haselkorn et al., 1989). Huchingson et al., (1977) Richards et al., (1978), and Haselkorn (1989) also found that a driver's familiarity with alternative routes influenced diversion behavior.

The ability of drivers to receive real-time traffic condition information and quickly adjust **enroute** travel plans is seen as a method for improving traffic flow. Jones et al., (1989) articulated that the effectiveness of route guidance systems is dependent upon drivers'

ability to improve travel times through dynamic path choice and time shifting. It was estimated that for individual opportunistic drivers on this corridor there is a potential to reduce travel times ten to twenty-two percent through departure time adjustment and fifteen to thirty percent through route switching.

Several researchers have theorized that real-time information influence **enroute** diversion behavior by improving driver perception of current travel conditions and conditions on alternate routes (Ben-Akiva et al., 1990; Khattak et al., 1991). It is clear that several factors must be accounted for: **enroute** behavior is a constant, iterative decision making process, day-to-day experiences and learning influence behavior, combination of past experience and current perceptions bias choice, and individual behavioral differences impact perceptions.

2.4.3 Influence of Real-Time Information on System Performance

Faced with the rise in interest of advanced traveler information systems, research in the latter part of the 80's turned to analyzing the effect of information availability on drivers and understanding the relationship between driver perception, memory, learning, and information acquisition. Issues were raised as to whether information would actually improve travel times for the individual and for the system as a whole, whether drivers with information acted different than drivers without, and what effects varied levels of information would have on drivers.

Arnott et al., (1990) inquired whether or not information is beneficial for traffic as a whole. They asserted that, when individual drivers can benefit from information, if all drivers receive and use information the system may be worse off. In addition, they make the claim that if drivers receive imperfect information they may be worse off than if they had no information. Their research was limited to one or two routes in parallel and only considered information provided to drivers before they departed. They ignored dynamic change caused by information provided on-route. Furthermore, their research assumed that drivers immediately use the provided information. Their research does not capture behavioral factors of repetitive trips, prior experience, or day-to-day adjustments.

Mahmassani and Jayakrishnan (1990) analyzed system performance and user response under different levels of information. They too illustrated that actions by local drivers may result in worse conditions for themselves and for the entire system. Their work simulated network flow while varying two parameters: (1) percentage of users who receive information and (2) the mean indifference band across the population controlling the propensity to switch. Their behavioral model was based on a simple satisficing rule that drivers switched routes if the improvement in travel time on alternate routes exceeded some personal threshold which measures the propensity to change.

2.5 Modeling Human Choice Behavior with Conflict Theory

As information technology has evolved from the Sixties to the **ATIS/IVHS** technologies of the Nineties, the goal has remained constant: provide drivers with enough quality information to influence driver choice and improve network performance. From early on, it was known that the ability to manipulate driver behavior through the content and availability of information systems was a critical element in traffic control.

Several theories were offered to explain the impact of real-time information on driving behavior and diversion. **Michaels** (1965) contended that traffic was attracted to highways, rather than surface streets, as a means to minimize tension of driving. He suggested that tension, frustration, and stress incurred while driving is a more important determinant of route choice than either operating costs or travel time. He also thought that direct measurement of attitude, rather than descriptive information about driving habits, is a better prediction of route choice. **Case et al.**, (1971) reported that information acquisition modified driving behavior, including reduction in anxiety and frustration.

Correspondingly, a driver's motivation to reduce delay was shown to be a major factor contributing to diversion and active information acquisition. **Heathington, et al.** (1971) found three significant attributes about drivers' decisions to divert. First, diversion was used to avoid delay, rather than desire to save additional time. Second, the severity of delay influenced diversion behavior. Third, drivers were more likely to divert en-route to work, than on the trip home. **Carlson et al.**, (1979) in a study to evaluate HAR on I-35W in Minnesota, showed that commuters concerned about travel time and delays actively sought information from the HAR. **Huchingson and Dudek** (1979) and **Huchingson et al.**, (1984) showed that the amount of delay in relationship to trip time impacts diversion behavior and that drivers have thresholds of tolerance with respect to delay.

Recent research done at the University of California Irvine (**Novaco et al.**, 1979; **Novaco et al.**, 1989) suggest that stress and other psychological factors have a great impact on drivers. These factors were found to influence a driver's perception of traffic congestion, arousal, and task performance.

These basic concepts of reducing tension, frustration, and anxiety, motivation to reduce delay, and desire to seek information are common in human behavior outside the realm of driving. Such emotions and actions have been widely studied in psychology and behavioral sciences and resulting theories applied to diverse disciplines such as consumer behavior and child development. It is therefore not a large step of faith to suggest that psychological approaches to human behavior may be used in a general sense and applied to driver behavior, as has been done in consumer behavior.

This section briefly outlines a series of theories on human behavior initially developed in psychology and since applied to other disciplines. Together, these ideas will form the theoretical framework of this research presented in depth in Chapter 3. The overview

involves four parts: a general description of conflict theory, the concept of tolerance to conflict and its impact on behavior, human reaction and response in conflict situation, and the role of information in perceiving and responding to conflict.

2.5.1 Basic Concepts of Conflict Theory

In analyzing human behavior there is no one science which provides a standard modeling technique or approach able to capture all complexities. Various approaches have been offered by researchers; yet, in the end, most of these approaches have borrowed from research in other disciplines. **Markin** (1974) put it aptly when he wrote in his book on consumer behavior:

“There is no single science of human behavior. Consumers are complex and sophisticated entities. Thus, there is no single way to approach the study of human behavior in general or consumer behavior in particular. Consumer behavior studies are based upon concepts and methodologies borrowed from such disciplines as economics, statistics, sociology, psychology, social psychology, and cultural anthropology. The consumer is a **biopsychosociological** being affected by many diverse and ambiguous stimuli. His behavior remains to be explained in terms of psychological, sociological, and cultural factors as well as biological and physiological phenomena.”

Although there are differences between driving behavior and consumer behavior, there is a close relationship which binds the two. Both sets of behavior are influenced by individuals' perceptions toward certainty and risk as well as expectations and aspirations defined through goals. In developing the theoretical formulation for studying driving behavioral choice, theories developed in consumer behavior research will play an integral part.

One of the theories central to the study of human behavior, and applied to the area of consumer behavior, is that of conflict arousal, motivation, and response. This theory asserts that humans are goal-driven and conflicts with goal attainment are responsible for arousing and motivating changes in behavior.

It has been documented that humans act either to address internal needs or in reaction to external forces. People are motivated to fulfill goals and the resultant activities are a function of all variables which arouse and direct behavior (Madsen 1964). In response to outside pressures, reactionary activity is manifested as behavioral response to expected or unexpected changes in their task environment which conflict with primary objectives and goals. **Mar-kin** (1974) suggests that goal-striving aspects of consumer behavior models defines the entire process as general problem-solving behavior. Problems by definition exist when goals are desired but there is uncertainty as to how best attain them. Therefore, all activities related to goal determination, treating and handling uncertainty, and choice “is consumer behavior when it is related to the acquiring of economic goods.” It follows that analyzing consumer behavior requires the analysis of all factors which affect these aforementioned processes.

Conflict arousal, combined with the constant pressures to succeed, provides the motivation for people to adapt their behavior toward meeting their goals. Arousal is the stimulation which evokes reaction, motivation is the behavior which effects reaction. This phenomenon has been observed by psychologists and behavioral scientists for many years in their studies of human behavior. Based on the ideas and theories developed by studying choice in this manner it is evident that driver behavioral choice lends itself to be analyzed in light of conflict arousal and response.

Over time, conflict has been used to describe those instances in which humans experience frustration and tension over competing or incongruous activities or goals. Psychologists have used conflict to describe situations where there is a significant correlation between stimulus and response. Berlyne (1960) suggests “when two or more incompatible responses arouse simultaneously in an organism, we shall say that the organism is in conflict.” Cofer and Appley (1964) summarize that conflict is a special case of two or more incompatible responses to frustration under conditions when a motivated organism is thwarted from reaching its goal behavior. Consumer behaviorists and decision analysts use theories of conflict to describe situations of frustration, anxiety, and tension that often lead to the inability of people to achieve desired goals. Markin (1974) states that several types of conflict situations are experienced by consumers and each results in different behavioral responses. Hansen (1972) contends that situational aspects combined with physiological arousal causes conflict among consumers. Response to conflict situations can be predicted by certain cognitive elements which will become salient during response. The response will be influenced by (1) amount of arousal, (2) motivation of decision maker during choice, (3) factors of the problem domain, and (4) associations among cognitive elements. Goicoechea et al., (1982) explain that conflict provides decision makers with a tension that motivates action through periods of frustration and dissatisfaction with the current situation.

2.5.2 Threshold of Conflict Tolerance

Within the study of conflict there are two different approaches for measuring and describing the effect of conflict on behavioral choice: the degree of conflict and the severity of conflict. The degree of conflict measures the amount of conflict and increases in proportion with (1) nearness to equality in strengths of competing response tendencies, (2) absolute strength of competing response tendencies, and (3) the number of competing response tendencies. Conversely, severity measures the effects of conflict. It is a function of the degree of conflict and other factors, such as behavior and individual perception (Berlyne, 1957).

The ability to withstand increasing severity of conflict may be analyzed through a threshold model of tolerable conflict. Tolerable conflict has been described in the literature (Hebb 1972; Schroder et al., 1966) as the degree of conflict severity above which people attempt to respond to the situation. Individual differences and experiences

lead to the specification of different threshold levels between decision makers. Hebb (1972) suggests that through increased experience individuals learn to endure larger degrees of conflict. Over time, threshold to conflict severity also increases as individuals are more certain and comfortable with their experiences. In addition, for each decision maker situational factors impact threshold levels on a trial by trial basis.

2.5.3 Reaction and Response to Conflict

Conflict arouses decision makers to react and respond to changes in the status quo environment. Hansen (1972) states that conflict may arise from two sources. First, changes in the environment arouses humans to react. Increased arousal combined with motivation for change triggers response. Second, conflict can be self-generated, resulting from expectations heightened through perception and prior experiences. Einhorn and Hogarth (1981) distinguish *conflict in judgement* and *conflict in action*. The former corresponds to conflict between subgoals or attributes influencing choice. The latter regards problem resolution and the decision to avoid or confront conflict.

The process of conflict reaction and response covers the time interval from when humans first experience conflict until the time after which the choice process ends, either when conflict is eliminated or when action is taken to circumvent conflict (Hansen 1972). Solving problems is often a task of avoiding or preparing to meet conflict. Monarchi (1972) states that conflict can be resolved in two ways: innovation and adaptation. Innovation refers to the search for new directions and altering one's actions or behavior in response to conflict. Adaptation alludes to a restructuring of objectives and values so that decision makers increase threshold tolerance and become more content with the current state.

There have been several conflict models developed to represent behavioral choice. Janis and Mann (1977) and Hogarth and Einhorn (1987), developed frameworks for general conflict models. Hansen (1972) developed a model for consumer behavioral choice which used theories of conflict and arousal, information acquisition, and salient cognition. He stated that behavioral choice is a dynamic process and itself consists of several levels of choice. Three central principles reflect this theme: (1) choices are initiated to satisfy needs, (2) conflict is inherent in choice (there is some inherent incompatibility that says one cannot obtain something without giving up something), and (3) decision makers resolve conflict by balancing benefits and costs of competing alternatives, including the "do-nothing" alternative.

2.5.4 Information Acquisition and Conflict

Information acquisition is a major part of behavioral decision theory. Humans seek to acquire information from external sources when current perception and memory are insufficient for prediction or evaluation purposes. Models of information acquisition aim

to analyze under what conditions humans seek to acquire information and how the information is processed and used to evaluate or predict in the short-term and learned from in the long-term.

Information is also a critical element of problem assessment and solution determination under conflict. In problem assessment, information helps decision makers to envision the extent of the conflict. Information is also useful for identifying solutions which were not realized. Decision makers approach information acquisition to **fill** in gaps of knowledge created by a lack in prior experience, memory, or poor current perception. The more familiar a decision maker is with a problem domain, there is less need for information.

Hansen (1972) states that arousal, based on conflict, stimulates cognitive processes. The complexity of cognitive process depends on the amount of arousal. Furthermore, the tendency to acquire information depends on the amount of “perceived conflict” (defined by anxiety, risk, and uncertainty) of the decision maker. Hansen claims that “the more conflict perceived, the more information will be acquired.”

Information acquisition and cognitive processing have a major impact on rational choice. **Hogarth** (1987) states that there are four consequences of limited human **information-processing** capacity which affect judgement: (1) humans have a selective perception of information, (2) the nature of human processing is generally sequential, (3) humans have a limited capacity to process information: they typically use heuristics or simple rules, and (4) people have limited memory. These limitations suggest that the amount of information provided to decision makers may not be as important as the method of presentation or the stage in the choice process at which it is presented.

The study of information acquisition and cognitive processing for decision making under conflict involves three separate topics. The first focuses on the effect of broadcast and exposure of information to decision makers. It is theorized that the manner in which information is presented and the type of exposure impact decision makers and their ability to comprehend and process information. Once information is acquired, there are two facets in which decision makers use it - prediction and evaluation. Prediction refers to judgements in the future or out of range of current perception. Evaluation refers to assessing current perceptions. Both instances use information to clarify understanding of choice domains and improve the ability to make decisions.

Hansen (1972) stated that for behavioral choice there are two key issues to address:

- (1) *Selectivity in Information Acquisition*: It has been shown that people are selective in what types of information they seek out and biased in how they use information. When searching for information people tend to fall under two categories. The first type seeks information which they are interested in; the second seeks information to support views. Bias impacts what people will read, attend, learn and remember.

- (2) *Information Exposure*: When consumers are exposed to information sources it is necessary to consider the availability of different kinds of information, the message content, and the receiver's salient cognitive structure. Each part in the exposure will have great effects on the consumer.

2.6 Interactive Simulation Approach

Route choice and driver behavior research centers on two main types of data collection, revealed preference and stated preference. Revealed preference data is collected by asking travellers what choices they made in real-world situations. Stated preference methods collect data based on what people say they would do under certain specified hypothetical or real-world situations.

Stated preference approaches have several advantages over revealed preference. The main advantage is that experiments may be specially designed to control for the alternatives and attributes of the desired choice set. In addition, stated preference approaches may be used to evaluate behavioral choice under unfamiliar circumstances. These advantages are important for the area of real-time information technologies and driver behavioral choice. Since advanced traveller information technologies have yet to be implemented in most cities, drivers have had little or no experience with them. Thus revealed preference studies would gain little knowledge on driver behavior impacted by real-time information.

Interactive simulation is a powerful tool for conducting stated preference studies, especially with regard to route choice. Good simulators can recreate real-world scenarios and elude from participants responses which are similar to what would be done in the real world. This ability to model choice is based on two factors: (1) the manner in which a simulator can effectively translate the real-world situation to the simulation environment and (2) the manner in which physical elements of the real-world, which actively play a role in the choice process, can be represented. In considering route choice and travel decisions, simulation can be productive method to isolate choice components and obtain "subjective estimations of choice factors" (Bovy and Stern, 1990).

Recently, interactive computer-based simulation has grown in popularity among transportation researchers. Programs have been developed to analyze both individual choice and system performance impacts. Urban Driving Simulator (UDS) (Leiser and Stern, 1988) was developed to study subjective time and speed estimations. IGOR (Interactive Guidance On Routes) (Bonsall and Parry, 1991) was implemented to study drivers' compliance with route guidance advice. Ayland and Bright (1991) describe an inlaboratory experiment using a interactive simulation designed around a commercially available computer game. This project intends to assess the potential of IVHS technologies for the Euronett project in Europe. Researchers at University of California Davis are using advanced simulation to study In-Vehicle route guidance (Kitamura and Jovanis, 1991)

Traffic simulator that make use of video imaging and multimedia presentation have been developed and are being tested. Allen et al., (1991) **describe** an in-laboratory study of in-vehicle navigation systems and diversion behavior. They developed an interactive simulator combining slide imaging combined with computer graphics. Other more advanced approaches, such as enthosopes and fixed-based vehicle simulators, have also been developed to study various aspects of driving. While these approaches are more realistic and better for analyzing physical factors of driving, they are very costly to develop and have not yet been used extensively (Bovy and Stern, 1990).

Other forms of simulation have been used in transportation. Mahmassani and Herman (1988) and Mahmassani and Jayakrishnan (199 1) discuss the use of non-interactive simulations to generate network conditions and other travel data for the purpose of analyzing route switching in the contexts of departure time variability and real-time information acquisition.

2.7 Proposed Modeling Approach

The approach proposed and presented in this study attempts to incorporate conflict theories developed in various behavioral science disciplines for investigating driver behavioral choice and the impact of real-time information. The methodology integrates several basic assumptions of driver behavior, well documented in the literature, and builds to a general framework of choice. There are several important aspects of this approach which differ and improve on prior research efforts. Unlike previous work, this approach inherently models drivers as rational goal-seeking decision makers. Changes in **enroute** travel patterns are solely a function of conflict arousal and the perception that there is increased uncertainty for goal attainment. In addition, this approach lends itself to study the driver, not merely observable actions. Although diversion behavior tells certain facts about the driving process, it cannot capture the entire decision making and behavioral processes taking place. It is certain that there are drivers who will not divert but change their goal set as a method for adapting travel plans and to reduce conflict. The functional relationships developed in the conflict model can be directly applied to analyzing impacts of external stimuli, such as real-time information, on driver behavior. Instead of looking for correlations and relevant factors which impact choice, this approach advances one step further by suggesting direct relationships to explain changes in driving behavior.

This theory, although only applied in this project to **enroute** travel behavior, may be expanded into a general theory of short and long-term, static and dynamic model of driver behavior. The principle of goal-directed behavior may be carried through the entire driving process to account for learning, habitual travel, changes in cognitive processing, and other individual characteristics which impact choice. In addition, from the standpoint of **ATIS** research, this approach to driver behavior will help to address many issues of research, development, and implementation of these advanced technologies.

CHAPTER 3

THEORETICAL CONCEPTUALIZATION

3.1 Introduction

With the evolution of **ATIS** technologies, several recent studies have theorized models of driver behavior and information acquisition. The complexity of the human decision making process combined with the multi-variate travel choice domain has made it difficult to develop a theory that covers all facets of the process. Similarly, technical obstacles, such as the limited real-world implementation of **ATIS** technologies, has made it difficult to collect data to test these theories and calibrate models of dynamic driver behavior.

This chapter presents a theoretical formulation of a driver behavior model based on the principles of conflict theory as discussed earlier. The issues of data collection and model estimation will be addressed in the following chapters.

3.2 Framework Overview

To develop an understanding of driver behavior, it is critical to understand the prime factors that influence behavior, namely perception, intention, and motivation. Observed travel choice is not always an accurate indicator of driving intention or behavior. This is especially true with respect to route diversion and changes in **enroute** driving behavior. When a driver is spotted turning onto a street designated by a bright orange sign as a detour route, there is little way to know if this action was intended as part of the trip plan or it was an actual diversion influenced by the **signage**. Similarly, a driver seeming to continue on a road rather than turning at an intersection may itself be a diversion if the driver had initially intended to change roads but later decided not to. Since it is typically impossible for the casual observer to know a driver's intended path or travel objectives it is difficult to recognize diversion behavior. It is likewise tough to estimate when exactly drivers determined whether or not to divert and what factors explicitly impacted this evaluation process. Aggregating to propose general principles is further complicated when under identical conditions drivers with similar goals and driving intentions act differently.

Recent studies have shown that dynamic evolution of driver choice is a complex process influenced by many factors including individual behavioral differences, individual cognitive processing ability, familiarity and experience, and the availability and accessibility of acquiring real-time information. Day-to-day experiences update cognitive mapping and provide drivers with a more certain estimate of travel conditions on which to rely for developing new travel patterns. Real-time information provides drivers with current

information to assist in assessing and adjusting current trip patterns. Behavioral differences in motivation, risk preference, and travel utility shape travel choices.

As of yet, no clear strategy has been implemented to develop a pure theoretical basis for modeling and predicting **enroute** assessment and adjustment behavior. It is generally agreed that **enroute** choice is triggered by changes in several factors including:

- (1) Drivers' perception and knowledge of current path conditions (delay, expected travel time, congestion level)
- (2) Drivers' knowledge (or perception) of the existence of alternative paths and travel conditions on these paths
- (3) Driver's degree of taking risks
- (4) Thresholds of tolerance to expected traffic conditions
- (5) Certainty of meeting travel goals or expectations
- (6) Impacts of information acquisition

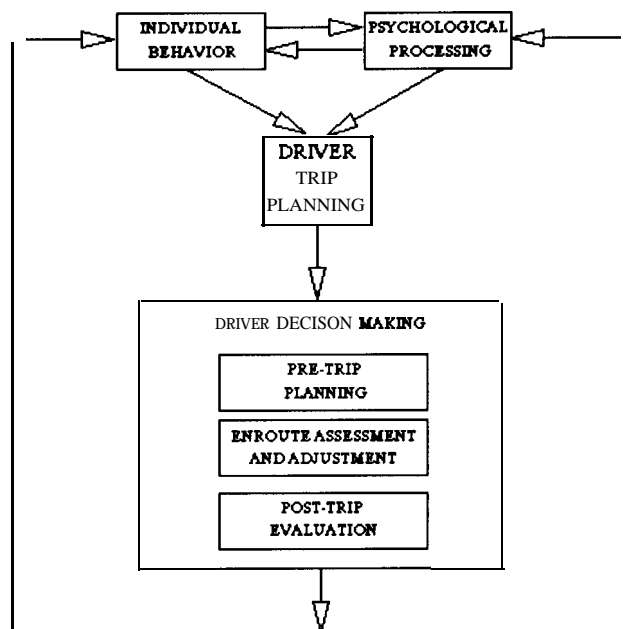
3.3 Theoretical Construct

This study proposes a theoretical framework to model **enroute** assessment and adjustment behavior that includes the six factors cited above. It is postulated that a conflict model combined with an overall goal-oriented approach to travel behavior will provide the basis for modeling **enroute** behavioral choice and may be extended for estimating a general model for static and dynamic driver behavioral choice. The sections that follow provide a more detailed explanation as to how these six factors contribute to the overall framework.

The proposed framework for modeling **enroute** driver behavioral choice is based on conflict theory and constructed through the relationships between driver behavior, cognitive processing abilities, and components of the decision making process shown in Figure 1. The general approach suggests that travel is defined by three stages: pre-trip planning, **enroute** assessment and adjustment, and post-trip evaluation. The first two stages involve direct decision making in real-time. The third stage is a longer-term evaluation of past trip-making success creating the link between past performance and future impression that shapes driver behavior over time.

Although the focus of this research is on **enroute** behavior, to enable a complete modeling approach it is important to note the significance of the other two parts of the cycle. Through the pre-trip planning process drivers define their initial travel plans, route choice and objective set. Both of these elements are important for analyzing driver's **enroute** behavior relative to their initial plans. Post-trip evaluation provides the ability to understand the long-term learning process that evolves from multiple trips. Over time, drivers acquire experience and greater knowledge of travel parameters. This increased awareness changes their perception and decision making capabilities.

Figure 3.1 : General Schema for Driver Behavior Model



It is proposed that **enroute** travel is characterized by 4 main components: (1) initial travel strategies (defined in pre-trip planning), (2) conflict arousal and motivation, (3) information acquisition and processing, and (4) travel adjustment. The **enroute** decision process is depicted in Figure 2.

The components of this generalized approach are summarized as follows:

Initial Travel Strategies : During pre-trip planning, a driver establishes a set of goals to be achieved. The relative importance of goal attainment is defined by a set of preference weights attributed to each goal. Depending on the units that measure each goal, the decision-making process may be specified as either singly objective (e.g., minimize cost) or multiobjective (e.g., balance a set of conflicting goals measured in varied units such as cost and time). It is assumed throughout the process that drivers are rational decision makers attempting to optimize their travel utility. All decisions reflect the goal set and the importance of attaining the specified objectives.

Information acquisition and cognitive processing have a major impact on rational choice. **Hogarth** (1987) states that there are four consequences of limited human information-processing capacity which affect judgement: (1) humans have a selective perception of information, (2) nature of human processing is generally sequential, (3) humans have a limited capacity to process information; they typically use heuristics or simple rules, and (4) people have limited memory. These limitations suggest that the amount of information provided to decision makers may not be as important as the method of presentation or the stage in the choice process at which it is presented. In the development of this theoretical foundation these biases are important for studying evolution of static and dynamic patterns of drivers' diversion and information search and acquisition behavior.

3.9.1 Biases in Information Search and Acquisition

Judgments are subject to biases on account of limited information processing capability and decision makers' ignorance toward optimal information processing and choice (**Slovic** et al., 1977). Biases are found throughout the decision making process and can have a significant impact on rational choice. **Hogarth** and **Makridakis** (1981) suggest that there are four primary locations of judgmental biases and key questions which each area addresses: information acquisition, processing, output, and feedback. **Hogarth** (1987) states that one cannot fairly evaluate the general ability of people to make decisions without considering those factors which hinder or facilitate good decision making or accounting for the criteria by which decisions are to be judged.

Information acquisition seeks to determine the salience of information to decision makers. Since information stems from memory and the task environment, relative salience is a function of one or both of these sources. There are a number of biases in this phase. The ease of recollection from memory influences perception of past events. There is also a tendency of people to judge strength of predictive ability by frequency rather than relative frequency. Moreover, concrete information is more salient in memory than abstract information.

The physical structure of tasks can lead to biases in information acquisition. The ordering of effects may lead people to believe that one effect is more dominant. Furthermore, deviations and exceptions in choice sets may influence evaluation and selection. In comparing alternatives to a reference, negatives in choice, such as travel delay, may have a bigger impression on memory and perception than positive variables, such as travel time.

Information acquisition may also involve some degree of selective perception. Humans have been found to seek information to confirm hypotheses rather than to objectively solve problems. Furthermore, the way that decision makers frame problem situations and view task environments influences solution. Anticipation of what one expects to experience biases what one actually does experience. Similarly, people simplify the structure of

Information Acquisition and Processing: Information assists drivers in their perception of travel conditions and in locating alternate travel paths. Through various technologies, such as radio or message signs, it is possible to acquire traffic condition or route diversion information. This information, when acquired by drivers, is internally processed in conjunction with other known information on network conditions and configurations stored in memory or viewed while traveling. Two important aspects of **enroute** driver behavior under **ATIS** are (1) under what conditions drivers seek information and (2) how the information is processed for decision making purposes.

Travel Adjustment: In response to conflict arousal and motivation, drivers process information from internal (memory and perception) and external sources to develop strategies to reduce conflict and improve their ability to attain their goals. The decisions that may be considered while en-route include: route diversion, goal revision, or do-nothing. It is assumed that all decisions are based on the notion of expected improvements in goal attainment. In cases where diversion is not a viable option, drivers may reduce conflict by reassessing their travel goals. Factors which influence response are discussed later in this paper.

3.4 Pre-Trip Planning

Antonisse et al. (1989) suggest that there may be several factors that influence route choice. They describe a process in which quantitative descriptor labels, based on available network data, are selected to measure a route's desirability. These criteria include minimize time, minimize distance, and minimize number of traffic signals, among others. Utility functions, containing systematic and random components, are specified for each possible alternative.

It is posited that a model for predicting individual driver's route choice for trip i at time t can be developed from the concepts of descriptor labels and link utilities.. It is assumed that an individual's travel behavior is influenced by a set of desired travel objectives. Each driver, for a specific trip i at time t , determines a set of travel goals to achieve. Drivers attempt to select an initial route choice strategy that will lead to the highest probability of meeting the travel goals. The actual routes selected will be determined through a driver's prior travel experience and the ability to forecast travel conditions when specific links are to be traversed. Under normative theories of rational choice, the pre-trip route decisions selected are presumed to represent either the optimal or **satisficed** choice for the driver for this single trip.

The set of desired travel goals may vary by drivers, trip purpose, or other spatial and temporal factors. The goals may be simple or complex, single or multiple. But for any

trip, it is assumed that the travel goals are well defined and represent the driver's state of knowledge of the system at that time.

For a given trip i at time t , the set of travel goals for driver d can be given as :

$$G_d^{it}(X) = [G_{1d}^{it}(x_1), G_{2d}^{it}(x_2), G_{3d}^{it}(x_3), \dots, G_{gd}^{it}(x_g)] \quad (3.1)$$

where:

$$\begin{aligned} G_{gd}^{it}(x_g) &= \text{Travel goal } g \text{ for driver } d \text{ at time } t \text{ for trip } i. \\ x_g &= \text{Set of performance indicators for goal } g. \end{aligned}$$

(Note: from hence forward, the superscripts i & t will be assumed)

Each driver has a method by which the goals are applied to determining travel strategies. A simple method for determining the relative strength of goals and to predict driver behavior is to invoke a *Weighted Objective Decision Method*. In this standard decision making model, the objectives are ranked according to preference and relative weights are assigned in proportion to the strength of preference. Utility for a specific route or link is measured by the additive sum of the expected value of goal attainment level multiplied by the relative weight. The selected alternative is the one that maximizes the expected utility.

$$\hat{U}^r = \sum_{g=1}^G W_g \hat{V}_g^r \quad (3.2)$$

where:

$$\begin{aligned} \hat{U}^r &= \text{Total predicted utility for route } r. \\ W_g &= \text{Relative weight for goal } g. \\ \hat{V}_g^r &= \text{Predicted expected value for goal } g \text{ on route } r \text{ (see below)}. \end{aligned}$$

Predicted Values

In the formulation above, the value of goal attainment for a specific route is based on a driver's perception and prediction of travel conditions and associated utility levels. \hat{V}_g^r represents the predicted **partwise** components of utility. For any trip at a given time there

is a known utility value, V_g^r , for a route. However the actual value of utility is unknown to the driver. Each driver has a perceived utility, \hat{V}_g^r , biased by personal behavior (i.e., risk) and uncertainty factor p :

$$\hat{V}_g^r = \rho_g^r V_g^r \quad (3.3)$$

The parameter ρ is a function of the driver's behavior, experience, and knowledge of the route and the system. At each time $t + \Delta t$, driver's cognitive processing is updated which in turn changes the factor $\rho = \rho + \Delta\rho$.

3.5 Enroute Assessment and Adjustment

Enroute behavior is a constant, iterative process, in which drivers are constantly reviewing travel conditions to assess whether or not the current path is optimal. When it is determined that the current path is sub optimal, drivers may decide to adjust their behavior. This section describes the proposed modeling approach, based on conflict theory, to explain **enroute** assessment and adjustment behavior.

3.5.1 Methodology

The assumption that the initial goal set and route choice selection are optimal under theories of rationality, implies that as long as the expectations are being met, change to the trip pattern should be unlikely. It is suggested that changes in **enroute** travel behavior must be initiated by overt need recognition and strong motivation. Conflict theory is a useful approach to model need recognition and motivation based behavior.

In conflict theory, activity is a direct reaction to need arousal and motivation. In the context of driving and travel behavior, the need is determined by the perceived difference between the desired goal attainment and the projected goal attainment based on current travel conditions. As drivers perceive that they may not be able to meet their travel goals by continuing on the current route there is increased desire to divert. Motivation to change is based on the availability and accessibility to alternate travel paths that a driver perceives will increase the potential for goal attainment.

3.5.2 Predicting Conflict Arousal

Drivers are constantly reviewing their travel progress with respect to the desired goal attainment. Changes in **enroute** behavior are initiated by increased conflict that eventually leads to salient need (to adjust behavior) recognition. Either internally, through perception

or memory, or externally, through information acquisition, the level of conflict experienced by a driver exceeds a tolerable threshold for the goal set.

Assessment is the first element of the conflict reaction and response process for **enroute** travel decision behavior. The assessment phase is initiated when drivers become more uncertain that their goals may not be met if they were to continue on the current path under the current travel conditions. As travel conditions change, and the conflict levels increase, the desire to alter travel behavior becomes more apparent. The threshold to conflict tolerance may be defined as the level of overall utility for a given route below which the route becomes undesirable.

The perceived utility of route r is given by:

$$\hat{U}^r < \dot{U}^r \quad (3.4)$$

where:

$$\hat{U}^r = \sum_{g=1}^G W_g \hat{V}_g^r = \sum_{g=1}^G W_g \rho_g^r V_g^r = \sum_{g=1}^G \rho_g^r W_g V_g^r$$

= Perceived utility on route r.

\dot{U}^r = Threshold utility level for route r.

3.5.3 Motivation and Response

Once significant conflict arousal has been inflicted, response is predicated on recognition of sufficient motivation. Motivation itself is difficult to measure, and is dependent on the availability of a response mechanism that is within reach and which, when executed, will yield significant improvement. The primary response to conflict arousal and motivation is diversion, the active decision to forego continued travel on the current path and instead pursue travel on an alternative. The level of motivation may be inferred by response -- either diversion or goal revision. Response is triggered by high arousal and motivation. Diversion occurs under high motivation; goal revision under low motivation. Both responses are based on the ability to reduce conflict and improve the utility of travel.

High motivation occurs when drivers project that diverting to an alternate path i will result in a significant gain in marginal utility. Diversion will occur if the perceived utility on the alternate path is greater than the utility projected for the current path by some improvement threshold η :

$$\hat{U} + \eta < \hat{U}^i \quad (3.5)$$

Such an improvement index has been used to measure switching propensity as a function of both perceived improvement and threshold of improvement. Likewise, it has been shown that several factors impact both the prediction of utility and switching propensity (Mahmassani and Jayakrishnan, 1990). First, there is some inherent uncertainty associated with estimating utilities. With imperfect information of travel conditions, the prediction is based on limited perception and memory. The inertia resulting from uncertainty that refrains many drivers from switching paths is based on the risk-taking behavior of drivers defined earlier by the parameter p .

Considering our example of a standard linear compensatory form of utility, the route switching rule (5) may be posed as:

$$\sum_{g=1}^G \rho_g^c W_g V_g^c + \eta \leq \sum_{g=1}^G \rho_g^i W_g V_g^i \quad (3.6)$$

Often motivation to switch depends on the set of alternatives. Under high conflict but low motivation it is possible that drivers will remain on course but revise the weights of the goal set. If alternate routes provide only marginal improvement, there may be little motivation to make the effort to divert. In such cases, goal revision can be a formidable compromise. Drivers can reduce conflict by reassessing trip forecasts and revising their expectations or relative weighting scheme. Adjusting the level of expectation through a reordering of the weights may reduce the levels of anxiety and frustration that were increasing as a result of the inability to meet previously defined objectives (i.e., reduce cognitive dissonance). If W' represents the new ordering of weights on the objective space, the revised utility of the current course of action is:

$$U'^c = \sum_{g=1}^G \rho_g^c W'_g V_g^c \quad (3.7)$$

and the route switching rule is based on:

$$\text{Max} (U'^c + \eta, U'^i) \quad (3.8)$$

These weights may change several times during the course of a trip in response to conflict. Each time, the decision maker reacts to the situation with the new set of parameters. Although the dynamic nature of evaluation and adjustment over several trips is unclear, it is likely that the experience will lead drivers to rethink the initial ordering of the weight set and to consider which orderings were more effective in reducing conflict during the trip. This paper does not attempt to focus on how goal revision impacts driver behavior in the

long run but asserts that it is a valid stage of the decision-making process that must be considered.

3.6 Treating Uncertainty

The **partwise** components of the utility function, V 's, are dependent on a driver's ability to perceive and predict travel conditions throughout the network. Among the goal set, G , there are both deterministic and stochastic components. Uncertainty associated with **enroute** decision making stems from two sources: inherent variability of nature and human prediction error.

Inherent variability of nature refers to the normal variation in travel conditions that a driver expects to incur. Examples of these cases include travel speed and density and number of red lights encountered. On a given link drivers may know its mean speed and mean density. It is likely that over a number of trips, the actual daily speed or density will vary from the mean. Similarly, for surface street travel, drivers may know the number of signalized intersections that they will encounter but from day to day the number of red lights that they will experience may vary. In both cases, these variables may be represented as probabilistic functions with known means and variances.

Prediction error presents a greater problem for modeling driver behavior. Prediction error is a function of individual knowledge and experience and may be biased by individual character. At any point in the network, drivers use their knowledge to predict the current state of the network (i.e. the severity of congestion on the current location) and the state of links or paths closer to the destination. The level of uncertainty associated with predicting travel states, closely tied to conflict arousal, impacts the **enroute** decision making process.

3.7 Information Acquisition and Enroute Behavior

Information acquisition and cognitive processing have a major impact on the abilities of drivers to predict network conditions and make rational route choice decisions. Within the framework presented, real-time information acquisition plays two roles in the trip making process. First, as part of the arousal process, traffic condition information of network links beyond the perception region tells drivers of impending problems. Second, drivers seek information for assistance with alternative route guidance in responding to conflict. These have been captured in behavioral choice theory as "combining information for prediction" and "combining information for evaluation and choice" (Hogarth, 1987).

The **enroute** travel decisions described here require the perception and prediction of travel conditions to determine whether or not goals will be attained. The limited geographical area of perception available to drivers **enroute** to their destinations makes it difficult to determine if the performance of links to be traversed is consistent with expectations.

Without the availability of external information, drivers would not be able to prepare themselves in case of imminent congestion. Limited knowledge also impacts evaluation and any subsequent choice of alternate travel strategies. Uncertainty or ignorance to the availability and performance of alternate routes reduces the likelihood of diversion. In many cases real-time information, either in the form of travel conditions or knowledge concerning possible diversion routes, would enlarge a driver's choice set and reduce the uncertainty or perceived risk associated with diversion.

The information acquisition and cognitive processing for decision making under conflict involves three separate stages. The first focuses on the effect of broadcast and exposure of information to decision makers. The manner of information presentation and the level of exposure impact decision makers and their ability to comprehend and process information. Once information is acquired, there are two facets to its use by decision makers - prediction and evaluation. Prediction refers to judgments either in the future or beyond the range of current perception. Evaluation refers to assessing current perceptions. Both rely on information to clarify understanding of choice domains and improve decision making capabilities.

Real-time information is useful to drivers for clarifying perceptions of traffic conditions and conflict arousal as well as for providing guidance in generating and analyzing possible alternate diversion routes. The value of information search is based on the expected benefits from actively pursuing data with respect to current perceptions and historical experiences. Behn and Vaupel (1982) suggest that the expected value of information is a useful guideline for determining whether or not to actively search for data. They state that information and acquisition may be valuable if they alter the decision maker's uncertainty about future events by changing the probabilities for various possible outcomes. Perfect information eliminates all uncertainty and permits faultless prediction; imperfect information changes the perception of uncertainty but does not eliminate it.

The search for information is generally predicated on the probability that useful information will be acquired. Two factors influence this decision. First, the information must be recognizable and understandable. For example, if a driver receives information of network conditions but does not recognize street names, the information is useless. Second, there must be the impression that the information will significantly improve prediction. When drivers are very familiar with networks and have high certainty as to network condition, there may be a very minor marginal return on receiving information.

The value of information is measured by the difference in expected values of utility for the choices with current information and after additional information has been acquired. By improving perception and prediction, information enables drivers to either reduce the bias parameter ρ or to improve the value estimation V . With the goal weights remaining constant the result is an increase in the expected utility U . This effect encompasses both known and unknown alternate routes. For those routes that a driver may have considered, information provides greater clarity on their relative attractiveness. For routes that drivers may not have considered as part of the choice set (having a very large uncertainty or risk

factor and small expected utility), information may greatly improve their stature in the choice set.

3.8 Impacts of Real-Time Information on Trip Making

Real-time information plays two roles in the trip making process. First, as part of the arousal process, traffic condition information about network links beyond the perception region tells drivers of impending problems. Second, drivers seek information for assistance with alternative route guidance in responding to conflict. These two uses of information have been captured in behavioral choice theory as “combining information for prediction” and “combining information for evaluation and choice” (Hogarth, 1987).

Enroute driving requires the perception and prediction of travel conditions to determine whether or not goals will be attained. The limited area of perception available to drivers makes it difficult to determine if future links to be traversed are performing up to expectations. Without the availability of external information drivers would not be able to prepare themselves in case of imminent congestion.

Limited knowledge also impacts evaluation and choice of alternative travel strategies. Uncertainty or ignorance of the availability and performance of alternate paths reduces the likelihood of diversion. In many cases real-time information, either in the form of travel conditions or knowledge concerning possible diversion routes, would enlarge a drivers’ choice set and reduce the uncertainty or perceived risk associated with diversion.

The potential impact of real-time information technologies is dependent on the classification of drivers and the availability and content of real-time information to be acquired. These issues impact both system performance and the ability to broadcast meaningful information to drivers in need. The efficiency of system performance under real-time information depends on the percentage of drivers receiving and following advice. It has been shown that when too many drivers switch their paths the system performance is worse off. For individual drivers, the need for real-time information changes throughout the trip process and varies among drivers. Information also provides different levels of marginal benefit to drivers. For system performance it may be critical to identify the category of drivers and type of information able to return the most benefit to the system.

3.9 Trends in Driver Behavioral Choice

To complete the theoretical formulation, it is necessary to introduce trends and biases which are known to influence conflict arousal, motivation, information search, and travel choice. These behavioral characteristics and relationships are part of the overall model as a contributor to goal specification and enroute adjustment. Behavior is not seen as the derivative of these factors but rather these effects impact behavioral choice as a consequence of goal attainment.

Information acquisition and cognitive processing have a major impact on rational choice. **Hogarth** (1987) states that there are four consequences of limited human information-processing capacity which affect judgement: (1) humans have a selective perception of information, (2) nature of human processing is generally sequential, (3) humans have a limited capacity to process information; they typically use heuristics or simple rules, and (4) people have limited memory. These limitations suggest that the amount of information provided to decision makers may not be as important as the method of presentation or the stage in the choice process at which it is presented. In the development of this theoretical foundation these biases are important for studying evolution of static and dynamic patterns of drivers' diversion and information search and acquisition behavior.

3.9.1 Biases in Information Search and Acquisition

Judgments are subject to biases on account of limited information processing capability and decision makers' ignorance toward optimal information processing and choice (**Slovic** et al., 1977). Biases are found throughout the decision making process and can have a significant impact on rational choice. **Hogarth** and **Makridakis** (1981) suggest that there are four primary locations of judgmental biases and key questions which each area addresses: information acquisition, processing, output, and feedback. **Hogarth** (1987) states that one cannot fairly evaluate the general ability of people to make decisions without considering those factors which hinder or facilitate good decision making or accounting for the criteria by which decisions are to be judged.

Information acquisition seeks to determine the salience of information to decision makers. Since information stems from memory and the task environment, relative salience is a function of one or both of these sources. There are a number of biases in this phase. The ease of recollection from memory influences perception of past events. There is also a tendency of people to judge strength of predictive ability by frequency rather than relative frequency. Moreover, concrete information is more salient in memory than abstract information.

The physical structure of tasks can lead to biases in information acquisition. The ordering of effects may lead people to believe that one effect is more dominant. Furthermore, deviations and exceptions in choice sets may influence evaluation and selection. In comparing alternatives to a reference, negatives in choice, such as travel delay, may have a bigger impression on memory and perception than positive variables, such as travel time.

Information acquisition may also involve some degree of selective perception. Humans have been found to seek information to confirm hypotheses rather than to objectively solve problems. Furthermore, the way that decision makers frame problem situations and view task environments influences solution. Anticipation of what one expects to experience biases what one actually does experience. Similarly, people simplify the structure of

problems based on experiences rather than trying to assess current problems as they really are.

Humans experience biases while processing information and evaluating problem situations. The most noticeable bias occurs when people rely on the success of previous choices and judgements. Unfortunately, the fact that previous choices were successful does not guarantee future success. The lack of consistency in judgement in different aspects of choice may also lead to biases. In driving, for example, people may react differently to problems encountered at the start of the trip versus those faced at the middle or end. Another bias in processing occurs when decision makers fail to revise opinions and perceptions of current situations in light of new information. Effects of the decision environment on the decision maker can also lead to biases. Pressure from time constraints or information overload may lead to impulsive or bad decision making.

3.9.2 Biases in Familiarity and Route Loyalty

It has been found that diversion behavior is biased by familiarity and route loyalty. Drivers who base decisions solely on past experiences are less likely to divert onto an unknown path. Similarly, drivers with better knowledge of network configurations and travel conditions are better predictors of traffic conditions and more likely to divert to lesser-known streets.

Loyalty seems to play a large role in arousal and diversion behavior. As route loyalty increases, diversion behavior decreases. It is hypothesized that experience and learning over time reshape the goal set with better estimates of ideal and minimum value levels. Commuters who experience delays on a regular basis become more immune to them and as a result their conflict level is diminished. In addition, loyalty to a particular trip pattern suggests some measure of equilibrium for the driver. Under these circumstances, additional information may not be searched for unless conflict arousal becomes too great. In these cases, changes are directly a function of the availability of a better travel pattern.

3.10 Summary

A theoretical formulation for modeling goal directed driver behavior and analyzing diversion and information search and acquisition has been presented in this chapter. The primary focus has been to represent the process in a holocentric framework where the desire to attain goals leads to behavioral responses developed over time. This approach maintains that conflict arousal and motivation must be present to initiate assessment and adjustment. The specification of the goal set combined with the certainty of meeting expectations are the basis for evaluating travel progress. The inability to achieve goals or the attainment of threshold tolerances raises frustration and anxiety levels which trigger need recognition. Aroused motivation, through the perception of significant improvement in goal attainment or ability to reduce conflict, impels response. Perception, experience,

knowledge, and risk lead to problem solution. If necessary, information search and acquisition is applied to improve decision making capabilities. Response to arousal, motivation, and information acquisition may involve diversion, goal revision, or both.

CHAPTER 4

DESIGN AND IMPLEMENTATION OF FASTCARS

4.1 Introduction

It is contended here that in-laboratory experimentation is a useful technique for conducting driver behavior studies. **FASTCARS** was developed to test the theories of presented in the last chapter and to estimate predictive models of driver behavioral choice under conditions of real-time information. The theoretical formulation presented in this report identified key stages in the driver choice process. **Pre-Trip Planning** incorporates goal formulation, destination choice, departure time choice, and initial route choice. **Enroute Travel Behavior** involves the four stage process of conflict assessment, motivation, real-time information acquisition, and behavior-induced adjustment through diversion or modification of travel objectives. This chapter details the manner in which **FASTCARS** was programmed to simulate these stages and effectuate data collection.

4.2 Program Description

FASTCARS is an interactive computer-based simulator that has been developed for in-laboratory experimentation to gather data for estimating and calibrating predictive models of driver behavior under conditions of real-time information. **FASTCARS** is not a pure driving simulator but rather simulates real-time travel decision making. **FASTCARS** models temporal and spatial factors, such as perceptions of speed and volume, time lapse, network familiarity, information acquisition, and travel goal specification and evaluation, which are the basic decision-making processes directly impacting driver behavioral choice. Its purpose is not to study the actual driving process, but rather to focus on the decision making aspects of trip making, including: goal specification, route choice, diversion, and information search.

The advantages of using **FASTCARS** over other data collection methods to study driver behavior are realized through the program's flexibility and completeness. The program encompasses the entire driving process from pre-trip planning through arrival at the destination. Players are required to make a broad range of choices including goal specification, route and lane changes, and whether or not to use available information technologies. Furthermore, many system variables, such as network conditions and information content, can be altered to represent different driving conditions. These features allow **FASTCARS** to replicate and model many of the decisions common to the trip-making process.

4.3 Simulating Network Travel

The central element of **FASTCARS** is in its ability to simulate travel along a traffic network and represent basic travel characteristics such as variations in travel speed, lane changing, road changing and modeling differences in freeway versus arterial roads. Additionally, the program was be designed to model temporal factors that impact travel choice, including congestion and incident delays and traffic signals. This section describes the coding of traffic networks for **FASTCARS** and how the input variables are used during execution of the simulation.

4.3.1 Coding a FASTCARS Network

Travel networks needed for **FASTCARS** are developed from three components: ‘streets’, ‘intersections’, and ‘links’. Streets are generic names of roadways that make up the network. Intersections, also called nodes, are locations at which two streets cross. Links are subsections of roadways that connect two intersections. **FASTCARS** networks are coded and stored in two data files ‘street data file’ and ‘link data file’. These files may be created with any text editor and saved to disk as standard ASCII text files.

The ‘Street Data File’ contains a listing of all the ‘Streets’ that are used to construct the travel network. Each street is coded with a numeric reference and a name identification. The number is used for coding nodes and links; the names are used in the simulation to visually identify roads being traversed. An example of a ‘Street Data File’ is illustrated in Table 4.1.

Table 4.1 Example of a Streets Data File

1	PRESIDENTS STADIUM
2	STADIUM WAY
3	STADIUM PARKING

53	FILLMORE AVENUE
54	LINCOLN AVENUE
55	HARRISON AVENUE

91	4 FREEWAY
92	21 FREEWAY
93	57 FREEWAY

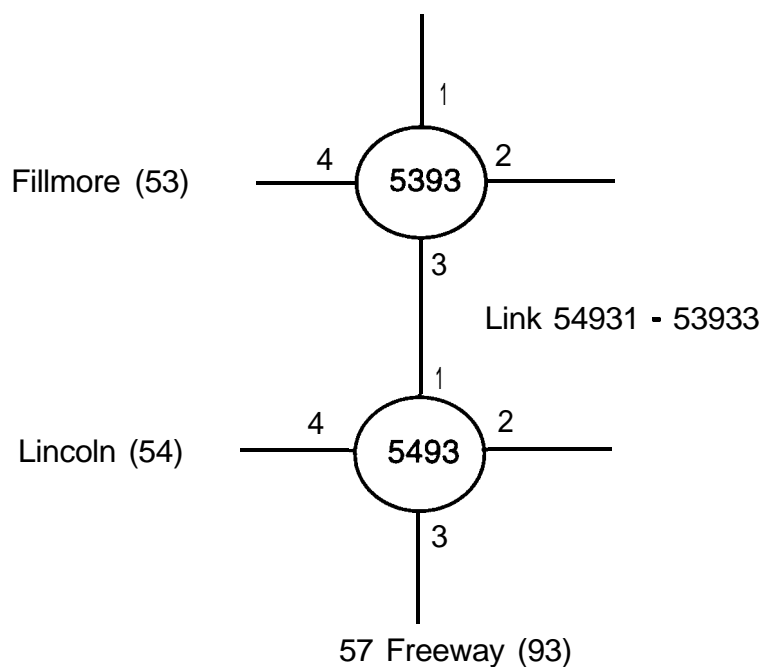
Intersections (also called nodes), are defined as a location where two streets cross each other. Intersections are connected by links to a maximum of four other intersections. Each intersection has at most four connectors that enter or exit it.

The adopted notation in **FASTCARS** is that intersections are assigned a unique number based on the two streets that cross to form it. The identification for the intersection is the combination of the two street numbers: Lower Street number-Higher Street Number. For the example street file shown, the intersection of Fillmore Avenue(53) and 57 Freeway(93) would be coded as '5393'.

Streets that cross more than once are denoted by a leading digit that denotes the direction of crossing. For example, should Fillmore Avenue cross the 57 Freeway twice, the intersections may be coded 15393 and 25393.

Networks are developed by creating a grid system of intersections connected by roadway sections called links. Figure 4.1 depicts an example of two intersections connected by a link. This figure also shows that each intersection has a maximum of four connectors, labeled 1-4.

Figure 4.1 Connecting Intersections



Links are denoted by a pair of numbers: 'From-Intersection Connector' & 'To-Intersection Connector'. In Figure 4.1, Link 5493 1 - 53933 connects Intersection 5493 (1 direction) to

Intersection 5393 (3 direction). Typically the directional indicators are assigned by special notation (i.e., 1=north, 2=east, 3=south, 4=west).

Each link has associated with it various characteristics such as number of lanes, speeds, and the like. The 'Link Data File' is therefore a data file that contains all of the link-specific information for the travel network. An excerpt from a sample link data file is shown in Table 4.2.

Table 4.2 Sample Link Data File

```

streets.dat
  FN      TN      D  #L  LEN  S1  S2  P(I1) P(I2)  V  W1  W2  UL  LNK
190952   452903  2  4  0.9 50.0 50.0 0.025 0.025  0  4  4  1  90
452901   116904  2  4  0.9 50.0 50.0 0.025 0.025  0  0  0  1  90
116902   115904  2  4  1.9 50.0 50.0 0.025 0.025  0  8  8  1  90
115902   190934  2  4  1.5 50.0 50.0 0.025 0.025  1  0  0  1  90
190932   114904  2  4  2.0 50.0 50.0 0.025 0.025  0  1  0  1  90
114902   252901  2  4  1.2 50.0 50.0 0.025 0.025  0  0  2  1  90
***
 91933   53931  2  3  1.1 50.0 50.0 0.025 0.050  0  8  8  2  93
 53933   54931  2  3  1.1 50.0 50.0 0.025 0.050 10  0  0  2  93
 54933   55931  2  3  1.3 50.0 50.0 0.025 0.050 010  0  0  2  93
 55933   93941  2  3  1.1 50.0 50.0 0.025 0.050  0  0  9  2  93
***
18563   18571  2  2  1.4 40.0 40.0 0.000 0.000  0  9  9  2  18
18573   18961  2  2  1.3 40.0 40.0 0.000 0.000  0  7  0  2  18
18963   18581  2  2  1.5 40.0 40.0 0.000 0.000  0  0  7  1  18
18583   18954  2  2  1.5 40.0 40.0 0.000 0.000  0  9  9  1  18
18952   18591  2  2  1.5 40.0 40.0 0.000 0.000  0  0  0  2  18
17513   17521  2  2  2.4 40.0 40.0 0.000 0.000  0  0  0  3  17
17523   117901 2  2  1.4 40.0 40.0 0.000 0.000  0  7  0  3  17
***

```

The link data file is coded as follows: The first line list the name of the street data file (streets.dat) that this link tile is attached to. The second line contains the variable labels. The remaining data records contain link characteristics as follows:

Columns 1&2 (FN, TN): From and To Intersection Numbers: Integers specifying From and To intersection number and directional indicators for link.

Column 3 (D): Link Direction: [1,2] integer column specifying if link is one-way [1] or bidirectional [2].

Column 4 (#L): Number of Lanes: This single digit integer specifies the number of lanes on each direction of the link

Column 5 (Len): Length In Miles: The length of the link in miles between the given nodes.

Column 6&7(S1, S2): Directional Average Speed: The average free flow speeds for each direction of the link. Column 6 is the forward speed; column 7 the reverse link speed. If the link is one way, the non-existent link speed is coded 0.0.

Column 8&9(P(I1),P(I2)): Probability of Incident: Probability of incident occurring on this link direction. Coded $0.0 \leq P(1) \leq 1.0$. Generally used only for freeway links.

Column 10 (V) : Variable Message Sign: A binary integer [0,1] specifying the presence of a Variable Message Sign on each direction of the link. 1 indicates presence of a VMS; 0 indicates absence.

Column 11 & 12: Road-Side Messages (W1, W2): Indicates a road side message identifier for the link. These messages are stored in a separate file and will be discussed in more detail later in this chapter.

Column 13 (UL): User Level: It is possible to tailor the network for varied familiarity. This column may be used to designate certain links to be known to players with certain levels of familiarity. This will be explained in more detail further on.

Column 14: Street Identifier: Indicates which street this link belongs to.

4.3.2 Coding Incidents

Incidents are probabilistically generated from the link file and stored external to the simulation. At the start of a simulation run, an incident data file is selected and its information accessed.

It was necessary to generate incidents externally for two reasons. First, having a set of known incident files provides better control over experiment design. Second, the voice board chosen for the experiment cannot be used to dynamically create voice messages. To emulate HAR, it was necessary to first generate the incidents and then create the radio messages to convey incident-related information. HAR message tiles are connected to the incidents by the incident data files.

Incident files are created from the probabilities assigned to each link in the data file. A separate module of **FASTCARS** was programmed to take a link file and generate incident files. The link data file is accessed and incidents are randomly generated and stored into files. A sample incident tile is displayed in Table 4.3. Each record contains 8 fields: incident category [1=place, 2=remove], intersection and directional link of incident, incident severity [1=minor, 2=major], start time, incident duration, mean speed at incident location, associated HAR file. If more than one incident file was generated for a specific network, **FASTCARS** can randomly select an incident file for each execution.

Table 4.3 Sample Incident Data File

1	9495	1	2	0.00	2148.00	5.0	incid1.vpi
1	5693	1	2	0.00	3802.00	10.0	incid1.vpi
1	1897	4	1	0.00	1772.00	23.0	incid1.vpi
1	9192	1	1	1014.00	1679.00	25.0	incid2.vpi
1	39092	1	2	1232.00	1699.00	8.0	incid3.vpi
1	9596	2	2	1585.00	1873.00	17.0	incid4.vpi
2	1897	4	1	1772.00	1772.00	23.0	incid5.vpi
1	9497	1	1	1854.00	1870.00	18.0	incid6.vpi
1	1594	2	2	1885.00	2369.00	9.0	incid6.vpi
2	9495	1	2	2148.00	2148.00	5.0	incid7.vpi
2	9192	1	1	2693.00	1679.00	25.0	incid8.vpi
1	25590	1	1	2787.00	1557.00	28.0	incid9.vpi
2	39092	1	2	2931.00	1699.00	8.0	incid10.vpi
2	9596	2	1	3458.00	1873.00	17.0	incid11.vpi
2	9497	1	1	3724.00	1870.00	18.0	incid12.vpi
2	5693	1	1	3802.00	3802.00	10.0	incid13.vpi
2	1594	2	2	4254.00	2369.00	9.0	incid14.vpi
2	25590	1	2	4344.00	4057.00	28.0	incid14.vpi

4.3.3 Visually Representing a FASTCARS Network

FASTCARS was programmed to display physical representations of the network to the players during the simulation. A special procedure to read and display .PCX graphics files was incorporated into the program. PCX graphics files showing network characteristics can be created from any graphics program capable of saving pictures to this format. In the case study presented in the next chapter, it is shown how these maps and the Link data files were used to simulate and analyze the effect of varied network experience and familiarity among players.

4.3.4 Inputs for FASTCARS Program

All of the initial inputs to the simulation are labeled in one file, 'fastcars.dat', which is read in at the start of the program. The first three lines contain path names for the node file, link file, and radio message file to be used during the simulation. The fourth record contains the departure and arrival times for the simulation. The fifth record lists three parameters: the origin node, the out arc of the origin node, and the destination node. The last record specifies four penalty parameters used in the scoring algorithm and corresponding to tuning in to highway advisory radio, turning on the in-vehicle navigation,

per minute assessment for using the navigation system, and the base penalty for goal revision. An example file is shown in Table 4.4. With this file it is easy to interchange network files, alter origin-destination pairs, and change departure and arrival time expectations.

Table 4.4 Sample Input File

inputs\baselink.dat	{ * Link data file	*
inputs\hsigns.dat	{ * Roadside Sign File	*
inputs\goals.dat	{ * Goal File	*
inputs\players.dat	{ * Player Data File	*
inputs\hiscore.dat	{ * Hi Score File	*
6.30 7.30	{ * Departure and Arrival Times	*
1058 1 103	{ * Origin and Destination Nodes	*

4.4 Pre-trip Planning

Just as the driving process begins with pre-trip planning; **FASTCARS** also begins by modeling pre-trip travel choices. **FASTCARS** is programmed to model destination , departure time, and initial route choice as well as specification of travel objectives. This section describes how **FASTCARS** simulates pre-trip planning stages.

4.4.1 Destination, Departure Time and Initial Route Choice

There are network specific decisions that must be made pre-trip within **FASTCARS**: destination, departure time, and initial route choice. The former two choices may be actual inputs to the **FASTCARS** program, the latter is reflected by a player's selected route to be traversed. Destination and departure time choices can be selected by the player or alternatively predetermined for the player. For the application to be discussed in this report, destination and departure time were variables that were controlled for and were predetermined.

During the pre-trip planning phase of **FASTCARS**, players are shown a set of maps representing the network configuration. These maps, developed for a specific experiment, are used by the players to determine initial route selection. When the **enroute** simulation begins, it is assumed that all links traversed up to the first diversion point (if one exists) will be considered part of the initial selected route.

4.4.2 Specifying Travel Objectives

The final choice to be made pre-trip consists of specifying travel objectives for the trip. Real-time decisions are made with respect to the perception of goal attainment; during post-trip evaluation drivers focus on how successful they were in meeting their goals. Correspondingly, goal specification and analysis is a central element of **FASTCARS** and is incorporated into the scoring system as a methodology for analyzing the actions and responses of participants.

In the game, the goal set and scoring function for each goal is predefined. The scoring functions are logistic functions, one for each goal, that normalizes the value of goal attainment for its goal to a score between 0 and 100. The normalization curves and goal set are described in detail to players at the start of the game: The shape of the normalization curves are calculated from ideal and minimum threshold points assigned to each goal. These points indicate plateaus of value levels. The ideal level marks the value above which drivers receive diminishing returns in marginal added value. The threshold levels indicate the minimum tolerable level for each goal. Below this level the value received decreases quickly. An example goal set and value levels are listed in Table 4.5.

Table 4.5 Example Goal Data Set

		Ideal	Normalized	Threshold	Normalized
1.	Minimize schedule delay (minutes) -	15.0	0.90	5.0	0.35
2.	Minimize travel time (minutes)	35.0	0.90	55.0	0.30
3.	Minimize number of stops(red lights)	10.0	0.90	20.0	0.30
4.	Minimize travel distance (miles)	23.0	0.90	35.0	0.30
5.	Minimize number of decision points	8.0	0.90	15.0	0.30

Travel Objectives

1. Minimize Schedule Delay: This goal suggests that drivers desire to be at their destination by a certain time. With the selection of departure and arrival times, there is a window in which drivers desire to reach the destination. The range of values for this goal implies that while arriving on-time is important, there is added value to arriving early and less value for arriving late. The ideal value also implies that there is often a diminishing return for arriving too early.

2. Minimize Travel Time: In many cases drivers do not have a set arrival time in mind but rather want to arrive as soon as possible. The ideal level specifies the practical shortest trip length that is perceived by the driver. Below this level, any added time savings have diminished return. The threshold level for this goal states that there is an upper limit for travel time which will be tolerated. In the example cited in the table above, the ideal and threshold values are set at 35 minutes (95%) and 55 minutes (40%).

3. Minimize Number of Stops: This goal captures a drivers tradeoff between freeways and surface links. Generally drivers prefer freeways because of the higher speed and fewer stops.

4. Minimize Distance: There are situations when many routes have similar travel times but differ in length. This goal attempts to measure if route distance is a significant variable in determining driver behavior.

5. Minimize Number of Decision Points: It is possible to want to minimize distance or travel time while not wanting to add complexity to driving associated with complicated routes. There is often a comfort or reduction in stress involved with maintaining a steady course with few decision points. The final goal, **minimizing** decision points, focuses on determining how this passive behavior impacts diversion and other trip-related decisions.

It is posited that travel objectives vary among individuals and are a function of individual character, trip purpose, and other factors. To capture this variation in preference among drivers, **FASTCARS** measured goal attainment through a weighted additive sum among the goal set. Each goal is weighted by a scalar to express its relative importance among the goal set to the player. Therefore, at the start of the game, players are asked to assign scalar weights to each goal in the goal set. These subjective weights, applied over the goal set reflect the players preferences. All decisions made henceforward may be analyzed with respect to these preferences.

This scalar weight matrix consists of a total of 100 points partitioned among the goal set. Each goal may receive any value between 0 and 100. Drivers are told that they can allocate points to as many goals as they desire (i.e. they may assign 0 weight to some goals) with the only stipulations being that all 100 points must be allocated among the goal set and at least 60 points must be placed on time-dependent goals (goals 1 and 2). This latter constraint is predicated on the assumption that time is most important in actual trip making (the other three goals help explain variations in driver activity) and ensures that players cannot achieve a “high score” by artificially choosing a goal set that excludes travel-time considerations.

This **weighted goal** set represents the definition of travel utility explained in the theoretical formulation above (see equation 3.6). At any stage of the game, the value of attaining

each goal, V , is given by the normalized score for that goal. When multiplied by the stated preference weight and the total score added over the goal set, the tally represents the utility, U , of the chosen path.

It is theorized that driver behavior and preference may change during a trip. Travel objectives and goal weights are trip and temporally dependent. To test this theory, **FASTCARS** allows players to adjust their goal weights during a session. At any point in the **game**, drivers are allowed to redefine their scalar goal weight matrix. This new matrix will be used to compute the final score. However, to ensure that players do not revise goals randomly throughout the game or as a “last ditch salvage effort” to receive a better score, goal revision is penalized by a numerical factor that increases the closer a player is to the destination.

4.5 Enroute Travel

The primary focus of **FASTCARS** is to model **enroute** travel behavior. This is accomplished by a player’s interaction with the program while the program simulates the driving process. This section describes the **enroute** simulator and the variety of choices that players make.

Once the initial route has been selected and the goal set established, the travel sequence begins. **FASTCARS** models travel on a link-by-link basis, ignoring system-wide traffic and focusing on traffic around the player. From the player’s perspective, the user interface is the most important part of any computer program. **FASTCARS** was developed with a simple, yet visibly interesting interface. The simulator is presented in a text-based animated format. The standard playing screen has four windows as presented in Figure 4.2 the “Network Viewer”, in the lower right side, the “Control Panel” in the lower left, the “In-Vehicle Navigation System” in the upper right, and the “Roadside Message Window” in the upper left.

4.51 Network Viewer

The primary window, the Network Viewer, is the large box which takes up the top two-thirds of the computer screen. This window presents the user with a “birds eye view” of a stretch of roadway currently being traversed. The current stretch of road is always shown in a vertical display with the user’s vehicle moving from bottom to top. Double vertical lines distinguish bi-directional traffic. At the base of the network viewer, the current road being traveled is listed. Cars are portrayed as rectangles. The player’s car is solid bright white. Other forward traffic is depicted by fuzzy red rectangles; opposite direction traffic by fuzzy blue rectangles.

The simulation progresses on a link section by section basis. At any given moment, the terminal depicts a 1.0 mile stretch of roadway in twenty 1/20th of a mile sections. Cars

move incrementally up and down the terminal $1/20^{\text{th}}$ of a mile at a time (this incremental distance may be adjusted). Based on the current speed of a car, the computer calculates the distance the car has traveled at each tick of the simulation clock. When the distance exceeds the next roadway increment, the car “jumps” to the next position. Spatial and temporal effects are driving are realized as vehicle movement is dependent on speed and relative to other cars in the system.

Players control two basic car movements, lane changing and road changing. Lane changes are initiated by a single keystroke. The cursor car turns into an arrow indicating direction of desired lane change. After a calculated lane-switch delay that accounts for travel conditions, the cursor is moved to the desired lane.

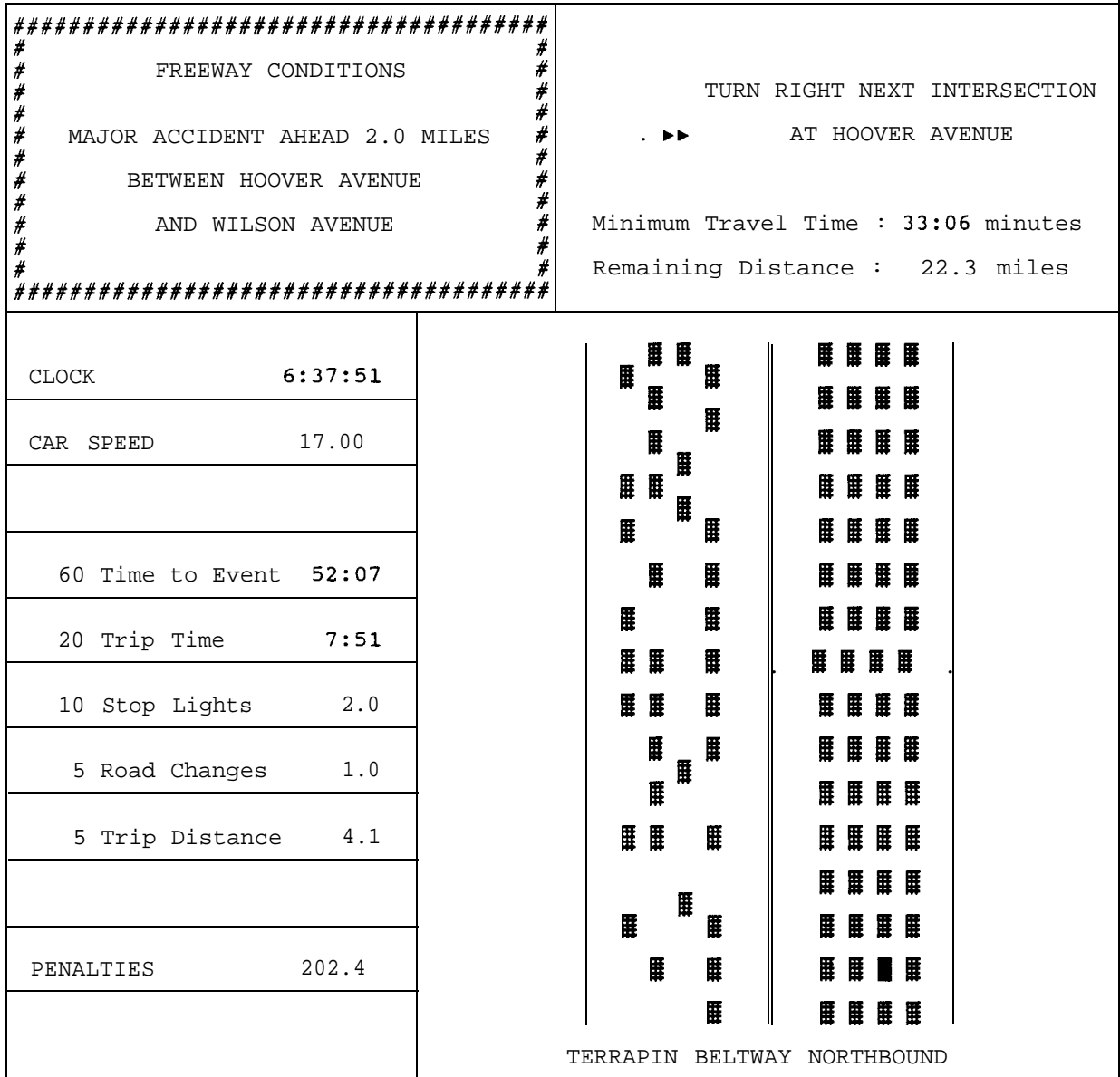
Road changes are available when the viewer displays a cross street. Available turning movements are indicated by arrows on either end of the cross street. The name of the cross street and turning direction is indicated next to the street. When a driver wants to make a turn, two steps must be followed. First, the driver must move to the correct lane. All turns from freeways are made from the rightmost lane. On surface streets, however, right turns are made from the rightmost lane, left turns from the leftmost lane. Second, the driver indicates the turning direction with a single keystroke. The cross street changes color and the arrow indicator blinks. When the cursor car intersects the cross street, it is guided automatically through the turn. If the cursor car is still in the wrong lane when the cross street is reached, the turn will not be executed.

The cursor car is moved to the next road section when it creates a successful turn, passes an intersection without turning, or when it reaches the halfway point on the display. There are a set of next display markers along the roadway to inform drivers when the display will be reset. Surface streets are distinguishable by traffic signals, two lanes, and generally lower speeds. Signals have set timings and on the red cycle, cars caught behind the stop line will queue and wait for the green cycle.

4.5.2 Control Panel

The control panel, on the lower left of the display, lists important system information. At the top of the display are the current simulation time and cursor car speed. Below that, the set of five goals are listed. To the left of each goal is the player’s selected goal weights; to the right is the accumulated score for each goal weight. These scores will be normalized at the end of the program to values between 0 and 100.

Figure 4.2 FASTCARS Visual Display



At the bottom of the control panel there is an indicator for penalty units assessed. Players are assessed penalties for using **ATIS** technologies. These penalties, that are subtracted from the player's score at the end of the game, are introduced to reflect the cost of information acquisition. It is expected that with no penalty units, players would use the information sources indiscriminately.

4.5.3 Emulating ATIS

FASTCARS presents drivers with two types of information: basic road signs and advanced traveler information systems.. The upper left box in the display is used to showcase basic roadside information signs as well as variable message signs. Basic roadside information signs were provided in the visual display to ensure that players have "standard" information regarding their current position relative to the basic network configuration. These basic signs include "Next Exit" signs for freeways and Roadside informational signs.

Next Exit signs display the upcoming Freeway exists along with the distance to the exit. An example of such a display is shown in Figure 4.3:

Figure 4.3 Sample Next Exit Sign

Lincoln Avenue	0.8
Fillmore Avenue	1.4
4 Freeway	3.6

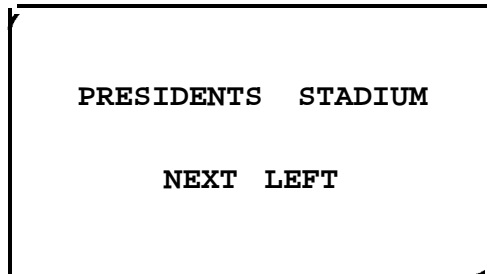
Roadside signs provide general directional signs such as "Stadium Next Right" or "Freeway Junction Ahead". Roadside signs are displayed at certain link locations as specified in the link data file. The messages themselves are stored in a special data file that is accessed at the start of the simulation. An example of a message sign file and how the message is displayed is depicted below in Figure 4.4. The integer coded in the link file corresponds to a line in the data file that is displayed as a message.

Figure 4.4 Roadside Signs

```
{* Example file with 11 coded messages *}
PRESIDENTS STADIUM NEXT LEFT
PRESIDENTS STADIUM NEXT RIGHT
PRESIDENTS STADIUM STRAIGHT AHEAD
TRAFFIC ADVISORY PRESS 'F5'
FREEWAY ENTRANCE NEXT LEFT
FREEWAY ENTRANCE NEXT RIGHT
FREEWAY ENTRANCE STRAIGHT AHEAD
SPEED LIMIT 55 MPH
SPEED LIMIT 40 MPH
DOWNTOWN NEXT 2 EXITS
DOWNTOWN NEXT EXIT

{* Sign as Displayed in FASTCARS *}

```



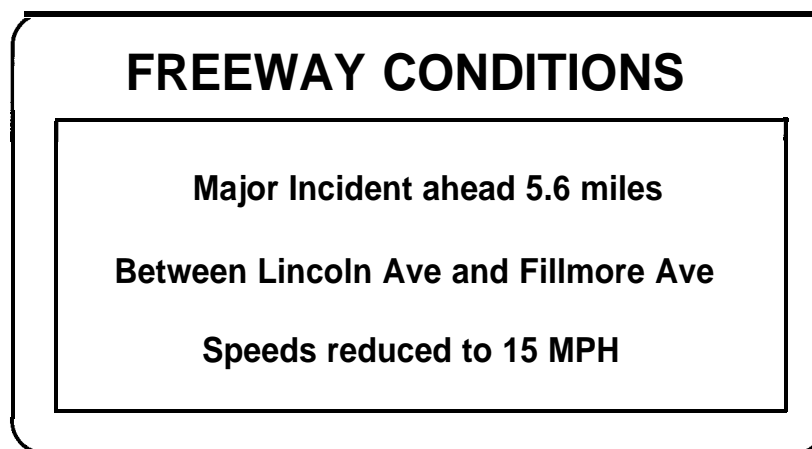
FASTCARS is equipped to emulate three types of advanced traveler information systems: variable message signs (VMS), highway advisory radio (HAR), and in-vehicle shortest time navigation system (IVNS). These were selected on the basis of their diversity of presentation and message content.

In the simulation, variable message signs are displayed at certain freeway locations so as to provide drivers with brief reports on the local traffic conditions on the current link. At points where messages are selected to be displayed, the program searches several miles ahead on the current freeway to gather data on the traffic conditions that are scheduled to be encountered. Based on the downstream condition, there are four possible message categories to be displayed. The program uses some simple heuristics to decide which message is to be displayed. The possible categories of messages are shown in Figure 4.5

Figure 4.5 VMS Messages

1. Freeway Clear Next 5.0 Miles
2. Minor Slowing Ahead, Speed Decreased to **xx** MPH
- 3 . Heavy Congestion Ahead, Speed Slowed to **xx** MPH
4. Incident Ahead mm Miles between **x** Avenue and **f** Freeway Interchange

{ * VMS Displayed in **FASTCARS** * }

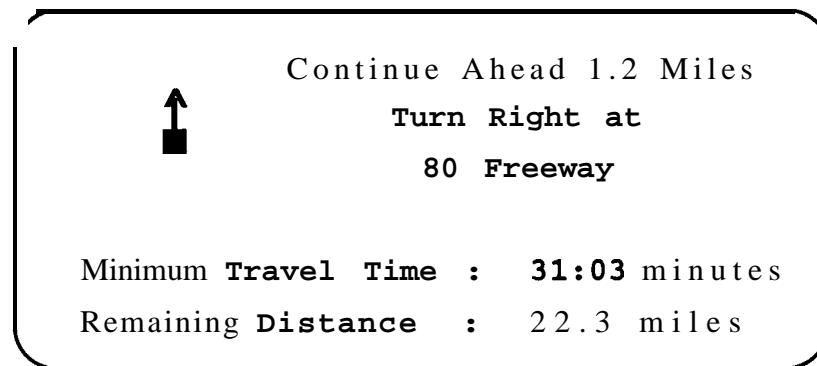


Highway Advisory Radio is the second information technology simulated. **FASTCARS** utilizes a Voice Adapter which allows players to activate pre-recorded radio messages containing relevant information on highway conditions and on the availability and accessibility of alternate routes. In the current version of **FASTCARS**, incident probabilities and speed distributions are assigned to network links. Before beginning data collection, a series of network profiles that distribute incidents on the network may be generated. Based on these network tiles, HAR files can also be prepared. At the start of the game the simulator randomly selects a network profile and set of HAR files to be used.

In-vehicle navigation systems offer drivers a direct source for finding the shortest path to their destination. Through a computerized system, IVNS typically gathers real-time information and instructs the driver where to turn. With IVNS, drivers do not receive traffic information nor do they have to make any predictions or calculations - they merely follow directions. The benefit of IVNS is that drivers who are unfamiliar with the network can adhere to the advice and take a shorter path to the destination. It does not, however, relate explicit traffic conditions; the best path may still be along a congested corridor.

FASTCARS emulates IVNS with a prototype in-vehicle navigator that gathers travel time information. The navigator is displayed in the top right corner of the visual display. When a new link is entered, **FASTCARS** calculates the shortest time path to the destination. This information is used to display in-vehicle navigation information. While activated, the navigator displays three pieces of guidance information based on the calculated shortest path: (1) suggested action for next intersection or freeway exit, (2) expected shortest travel time to the destination, and (3) distance from the current location to the destination via shortest time path. The guidance is presented both textually and graphically. Graphically, arrows point to the direction in which the driver should continue at the next intersection or freeway exit to follow the shortest time path. The same information is presented in sentence form. A sample **IVNS** display is shown in Figure 4.6.

Figure 4.6 IVNS Display



4.5.4 Penalty Assessment

To study the tradeoffs between goal revision and route guidance and to measure the need for real-time information, **FASTCARS** has established a system of assigning penalties which are deducted from a player's score. The number of penalty units to be assessed for each is specified as an input to the system. The former penalty assessment, for goal revision, was explained in an earlier section. This penalty measures the value of goal revision and not changing routes versus diversion.

To control for random use of **ATIS** technologies, players are assessed a small penalty for using HAR or IVNS. Radio penalty units are one-time lump sum levies assessed at the time the radio is turned on. Penalty units for using the navigator are metered. A base penalty is incurred for turning the navigator on. Additional penalty units are accumulated per minute of usage. Administering penalty units helps to determine how useful information acquisition is to a player by assigning a "cost" to the potential benefits

provided by acquiring information. The value of the penalty, the conditions under which the information is sought, and background data on player profiles are key indicators for estimating the impact of information on driver behavioral choice.

Administering penalty units help determine how useful information acquisition is to a player. The value of the penalty, the conditions under which the information is sought, and background data on player profiles are useful to estimate the impact of information on driver behavioral choice. Actual analysis of driver behavior and information acquisition is discussed with a full case study in the next chapter.

4.6 Post-Trip Evaluation

At the conclusion of a **FASTCARS** program, the player is informed of his score. Each of the objectives is normalized to a score between 0 and 100. Using an additive utility model, the normalized scores are multiplied by their respective weights added together. Any accrued penalty units are deducted and the resultant total is the final score for the game. An example of the final score display depicted in Figure 4.7.

With repeated trips it is possible to study the learning and day-to-day adjustment process of drivers. Over time one can observe how players changed goal weights, initial route selection, and game strategies in trying to improve their score.

Figure 4.7 Final Score Display

RESULTS FROM FASTCARS SIMULATION				
	Final		Normalized	
	Weights	Value	Score	Index
1. Arrive 15 Minutes Early	65.0	5.33	79.62	4777.49
2. Minimize Travel Time	20.0	12:36	65.78	1315.64
3. Minimize Stop Lights	10.0	0.00	99.12	991.24
4. Minimize Road Changes	10.0	10.00	66.14	661.37
5. Minimize Trip Distance	0.0	24.80	91.05	0.00
			SubScore	7745.73
			Penalties	356.67
			TOTAL SCORE	7389.06

4.7 Data Outputs

Besides the ability to simulate driving, **FASTCARS** is an effective data collection and storage tool. During playing sessions **FASTCARS** records two data files which can be used at a later time to analyze a participant's behavior. The first file records a list of keystrokes and clock times for each action. A sample output file is illustrated in Table 4.6.

Table 4.6 Sample Keystroke File

```

basecars.dat
  4.80      75    1    80.0    0.0    10.0    10.0    0.0
 533.62    59    1    80.0    0.0    10.0    10.0    0.0
 614.80    75    1    80.0    0.0    10.0    10.0    0.0
 615.40    75    1    80.0    0.0    10.0    10.0    0.0
1023.10    77    1    80.0    0.0    10.0    10.0    0.0
1023.70    77    1    80.0    0.0    10.0    10.0    0.0
1025.80    62    1    80.0    0.0    10.0    10.0    0.0
1350.62    75    1    80.0    0.0    10.0    10.0    0.0
1431.50    67    1    80.0    0.0    10.0    10.0    0.0
1526.37    59    1    80.0    0.0    10.0    10.0    0.0
1812.30    77    1    80.0    0.0    10.0    10.0    0.0
****

```

The first line indicates the input file used during that execution. The rest of the file contains **recod** fields that record each keystroke. Each record has eight fields: the first indicates the system time of keystroke (in seconds) the second and third fields combine to form a numerical representation of the keyboard stroke, and the final five fields represent the goal weights assigned by the player. The third column is a boolean vector of **[0,1]**. One indicates that the keyboard stroke was an extended key code (i.e., a letter combined with the "Control" or "Alt" key, or a function key). A zero indicates that a regular character was typed by the user. For example on line one of the file, the keystroke **[615.40 75 1]** indicates that the left arrow key was hit (indicating a left lane change) at time 6 15.40.

The second file which is saved is an event data file. This file records a list of important events which took place in the program. Player actions such as road and lane changes, turning on information systems, and revising goals are recorded as well as system events such as display of road side signs and road advancement. Along with the event type, each data entry also includes relevant system information of event times, current road, whether or not information technologies are on, and projected scores. These data provide a full account of what was taking place in the simulation at the time of a player decision.

The file is split into three sections. The first section, consisting of the top four lines, lists the final score for the player and answers to a series of personal questions asked at the conclusion of the trial. The second section contains two record of five data cells. These records correspond to the initial and final set of goal weights submitted by the player. The final section of output lists the system events. An example of the output event file is shown in Table 4.7.

Table 4.7 Sample Event File

```

6 - 10 - 1992
inputs\baselink.dat
inputs\goals.dat
9
  6.30   7.30   2086.72   1446.93
  1058   103

PLAYER NAME      2497   4   3   9543.28
5           5           5           2           5           3
8           5           5           4           1           1           0
1 0 2  1058  1858      0.00      0.00 0 0      0.00 35.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 2  1858  45890 3489.19 110.70 0 0      1.09 36.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
3 0 1  45890 49096 3316.12 283.61 1 0      2.90 41.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  49096 45790 3251.56 348.11 1 1      3.96 60.00 1 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  45790 45690 3191.00 408.62 1 1      4.95 63.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  45690 49094 3072.59 526.92 1 1      6.96 65.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  49094 45590 2996.71 602.70 1 1      8.15 57.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  45590 45490 2922.24 677.08 1 1      9.24 49.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  45490 45390 2833.45 765.76 1 1     10.83 65.00 1 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  45390 19097 2766.79 832.34 1 1     11.82 51.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  19097 11790 2642.67 956.31 1 1     13.63 58.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  11790 19095 2560.59 1038.29 1 1     14.92 62.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  19095 45290 2459.29 1139.47 1 1     16.41 49.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  45290 11690 2407.94 1190.76 1 1     17.30 63.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  11690 11590 2344.38 1254.24 1 1     18.19 51.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  11590 19093 2123.16 1475.19 1 1     20.10 30.00 2 0 0 65.0 25.0 5.0 0.0 5.0 0.0
5 0 1  19093 11490 1877.43 1720.83 1 1     21.54 25.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
3 0 2  11490 214 1739.56 1858.69 1 1     23.52 0.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
4 0 2  214 203 1696.77 1901.48 1 2     24.02 43.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
3 0 2  203 103 1553.81 2044.45 2 3     25.39 44.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0
2 0 2  203 103 1446.93 2151.45 2 4     26.17 26.00 0 0 0 65.0 25.0 5.0 0.0 5.0 0.0

```

4.8 Summary

This chapter has presented the development of FASTCARS, a simulator designed for collecting driver behavioral choice data. **FASTCARS** was modeled after the three main aspects of driver behavioral choice which were identified earlier: goal attainment, **enroute** decisions, information acquisition.

To capture goal-directed behavior, **FASTCARS** employs a scoring mechanism based on goal attainment. Players develop a goal set in the planning stages before beginning the simulation. Their final score is based on a composite algorithm which takes into account the final set of weights assigned to the goal set and the attained value for each goal.

FASTCARS models the driving process and the frustrations and anxieties associated with driving, through its life-like environment. Spatial and temporal effects of driving are experienced during the trial and the effects on driver behavioral choice may be examined. Conflict and motivation are seen by the reaction and response to traffic conditions. Information search, route diversion, and goal revision indicate that thresholds of conflict have been reached and players have become motivated to adapt.

For evaluating the impacts of real-time information technologies on driving, **FASTCARS** has been equipped with three prototypes of advanced traveler information systems. Variable message signs, highway advisory radio, and in-vehicle navigation provide drivers with real-time information in different formats and contents.

FASTCARS may be used for various experimentation purposes. Through directed input files, **FASTCARS** can be programmed to simulate different network configurations and trip types. It is possible to control network conditions, format of radio messages, departure and arrival times, as well as origin and destination nodes. For data analysis, **FASTCARS** provides a detailed listing of system events containing several **environment-**related parameters such as event time, location, speed of vehicle, and projected scores based on specified goal weights.

CHAPTER 5

FASTCARS APPLICATION : SPECIAL EVENT TRAVEL

5.1 Introduction

This chapter discusses a application using **FASTCARS** to study special event traffic under real-time traffic condition information. The case study application formulated and implemented was designed after the city of Anaheim California and the IVHS project being conducted therein. The initial section of this chapter discusses Anaheim and the need to model special event traffic. The remainder of the chapter details the case study including the design of the network, model parameters, and experiment hypotheses to test.

5.2 Application Setup

The case study prepared for using **FASTCARS** was constructed around a hypothetical city and a special event trip to the city's stadium. This section discusses the framework for the case study by describing the network layout of the hypothetical city, the control structure for the experiment, and some minor additions programmed in **FASTCARS** to facilitate data collection and analysis.

5.2.1 Hypothetical City Layout

A hypothetical model of a city and **ATIS** system was developed for the case study. This city, Terrapin, is depicted in Figure 5.1. The Terrapin traffic network coded for the case study is a system of arterials, freeways, and a beltway that circles the inner city. Both the beltway and freeway have higher free mean speeds, the difference being that the beltway has four lanes in each direction while the Freeways only have three. Arterials are coded having two lanes in either direction.

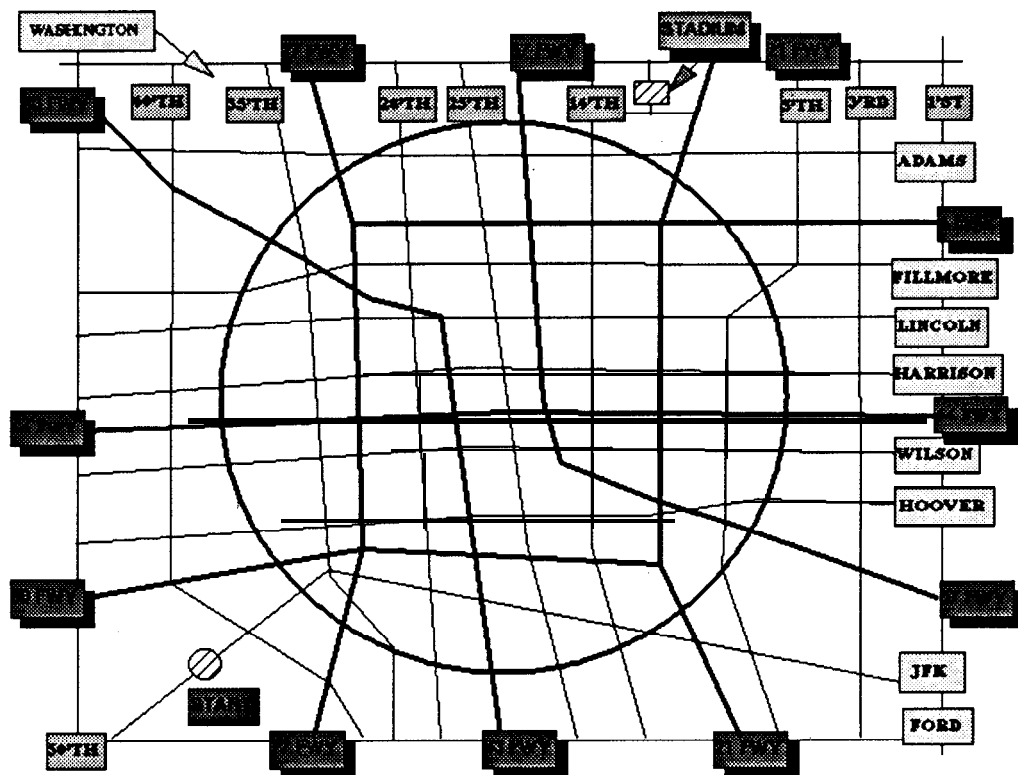
The traffic network in Terrapin was well planned and as a result lies in an almost grid-like structure. Arterials and freeways are placed in a general order, almost consistent with the manner prescribed in the United States. Odd numbered freeways in Terrapin run generally North-South with higher numbers to the West. East-West Freeways in Terrapin are even-numbered with higher numbers more Southernly.

Surface streets are located in similar fashion. North-South arterials are denoted by numbered streets (i.e., 50'th St, 25'th St, etc.) with 50'th St. being Westmost. East-West

arterials are denoted as avenues named after past Presidents (Terrapin being quite the All-American city) running from Washington Avenue in the North to Ford Avenue Southmost in the city.

For the experiment the destination chosen is the fictitious 'Presidents Stadium' located in the northeast quadrant of the city. Players are assumed to reside in the southwest quadrant. Each location is visibly marked on the map.

Figure 5.1 Layout of Terrapin Traffic Network



5.2.2 Modeling Driver Familiarity

Level of familiarity with network configuration and conditions is one of the variables controlled for in the application. As explained in the previous chapter it is possible to assign levels of familiarity to players by drawing maps with varied levels of detail. Players are allowed to look at these maps throughout the game without penalty. When the set of maps is accessed by players, the game pauses until the player is ready to continue. The

first time a player uses FASTCARS, the program randomly selects a familiarity level. Thereafter, players can move to the next level of familiarity after completing several trials. For this study, three levels of detail were designed: novice, intermediate, and expert. Each level of player is assigned maps as follows:

Novice

Novice players are assumed to be drivers with little or no experience driving on the network. Their network was developed having **only** a few of the available freeways and stadium accesses drawn on it. Therefore they are provided with only two maps, the first detailing the network as displayed for them and the second displaying distances along freeway links.

Intermediate

Players with more familiarity are assumed to have fairly good knowledge of the freeway system but limited experience on surface streets. In addition, from previous freeway travel intermediate drivers begin to have a sense of mean travel speeds. Intermediate drivers are therefore equipped with three maps: general network drawing, freeway distances, and freeway speed distributions.

Expert

Expert drivers have much experience driving the freeways and arterials in the city. They are therefore given a more detailed set of maps. Experts are equipped with five maps containing information on general network layout, freeway distances, freeway speeds, probability of incident occurrence, and surface street speed distribution.

5.2.3 Measuring Players' Risk Profile

Players' risk preference is a variable thought to impact driver behavioral choice. To capture some measure of a players' risk profile, the first time a person plays FASTCARS, the program begins by asking the player to respond to 10 personal questions. The first question asks the players gender. The second seeks to determine the players experience driving in urban traffic. Questions 3-10 ask players to respond on a scale of 1 (strongly disagree) to 5 (strongly agree) to statements that infer elements of risk taking. These questions, modeled after the work done by Khattak et al., (1991) are used during data analysis to determine factors impacting **enroute** behavior. Table 5.1 lists these questions as posed by FASTCARS.

These behavioral questions are only asked the first time that a player uses FASTCARS. Thereafter, the answers are stored in a special players data file that records various additional player statistics including level of familiarity, number of times played, average score, highest score, and last score.

Table 5.1 Risk Profile Questions

1. I am an aggressive driver
 2. I get impatient quickly if I have to wait
 3. I like discovering new routes to get someplace.
 4. I sometimes do things just to see if I can.
 5. I am willing to take risks to avoid traffic delays.
 6. I would rather take a little longer to use a route I know well.
 7. I prefer diverting to a surface street to avoid freeway congestion.
 8. I would rather take a route having higher speed even if it has longer distance
-

5.2.4 Modeling Incidents

The application was programmed to simulate both minor and major freeway incidents. From the incident probabilities assigned to each link coded in the link file, ten incident files were generated, and corresponding HAR files recorded. At the start of each simulation, **FASTCARS** randomly selects one of the ten incident files to use during the program. By having a large number of incident files, players will experience different levels of congestion and it will be more difficult for one person to influence another's perspective of the simulator. Furthermore, it is also possible to study longitudinal impacts of travel because over repeated trips, players will adapt their behavior based on their ability to recognize traffic patterns and identify incident probabilities.

5.2.5 Determining Diversions

To determine diversion points, **FASTCARS** was programmed to query the player at each road change to determine whether the road turn was a continuation of the current planned route or a diversion from the current route. To confirm first diversion points, at the end of the simulation, players are asked to identify their initial route choice.

5.3 Experiment Design Specification

The case study experiment was designed as a prototype testing of the simulator and theoretical process. Players were recruited from around the university population and included students, professors, and administrative personnel. Twenty-seven people participated in the study. Each participant played at a minimum two and **upto** a maximum of ten sessions. A total of 108 trials were collected.

The simulator was set up in a vacant office consisting of only the personal computer and external speaker necessary to emulate HAR. Initial sessions were conducted under the guidance of an instructor who explained the workings of the simulator; successive trials were performed at the players' convenience.

5.4 Controlling the Data Set

To control the variability in the simulation, several parameters were preset. All trials were performed with the identical origin-destination pair and all players had the same departure and desired arrival times. The set of five travel goals, associated normalizing functions, and penalty units for using **ATIS** technologies remained constant over all players. Variability among the players was captured by each player's user level of experience, specification of goal weights, initial route choice, and **enroute** decision processes.

5.5 Experiment Hypotheses

In addition to the theoretical hypotheses stated in earlier chapter connected to the theoretical formulation and model specification, the simulator and case study provided an opportunity to test several hypotheses. This section briefly discusses various expectations that were associated with the development and implementation of FASTCARS.

5.5.1 Player Performance

As explained in previous chapters, the scoring was designed around a linear multi-attribute utility function where the goal weights are multiplied by the resulting normalized goal scores. The total maximum score a player could achieve is 10,000. During the simulation, scoring is influenced by many factors. Under ideal-flow conditions it is expected that scores should range between 8500-9500 depending on the initial route **slected**, specified goal weights, and the manner by which players navigate the network. Should a player select a route having high congestion or incident, it is expected that performance will be reduced. Combinations of severe traffic congestion and unlucky route choice can lead to poor performance and scores below 5000.

It was expected that players selecting routes without severe congestion would receive higher scores, independent of their experience and user level. Expert and novice players selecting the same initial route and experiencing similar traffic conditions should be expected to receive similar scores. It was rather expected that variations among players and scoring would be realized with respect to diversion behavior and acquisition of real-time information.

5.5.2 Information Acquisition

There are several factors to influence players to acquire information. It was expected that two of the factors that would be likely to impact acquisition are the perceived severity of traffic conditions and the interaction with other **ATIS** technologies. While some players would be expected to use HAR or IVNS as a proactive, or preventative, strategy; it was posited that a majority would be reactive, using HAR or IVNS after initially being aroused by conflict. Moreover, it was posed that information acquisition is a joint effect. Players would be more likely to use HAR in conjunction with VMS messages encountered. Similarly, players use of IVNS would be influenced by VMS and HAR.

As explained in previous chapters, the scoring was designed around a linear multi-attribute utility function where the goal weights are multiplied by the resulting normalized goal scores. The total maximum score a player could achieve is 10,000. During the simulation, scoring is influenced by

5.6 Summary

This chapter briefly described a special events application that was implemented with FASTCARS. The subsequent chapter details data analysis and model estimation resulting from the experiment documented here.

CHAPTER 6

DATA ANALYSIS

6.1 Introduction

The theoretical formulation of the driver behavioral model, based on conflict arousal and resolution, as described in Chapter 3 was based on several hypotheses and theories. With the data collected from the case study, several data analysis techniques were used to test the postulated theories.

This chapter begins to describe the data analysis process. The chapter first discusses how the data collected from the case study was processed for analysis. The chapter then presents a series of descriptive statistics, including frequencies and category analyses, performed to provide an overview of the data set and the relationships between the variables.

6.2 The Data Set

Each **FASTCARS** trial produced an output event file listing each system event (refer to section 4.8 and Table 4.10). System events were defined as road changes which included **left turn, right turn, and ahead**; and information events, recorded when players looked at the maps, turned on the radio, or initiated the in-vehicle navigator. These records include system specific data to capture the trip status at the time of the event. Each line incorporates twenty variables including event type, diversion indicator, from-node and to-node labels, values of five travel objectives, current travel speed at event, indicators for VMS, HAR, IVNS, values of player's goal weights, and penalty units accrued. The event file also records trial specific data and player specific data. Trial data include date of trial and input files used in the trip. Player variables include answers to behavioral questions and post-simulation questions.

A file listing each player and player-specific variables is also stored. This player data file lists trial historical information, such as average and highest scores, and answers to the ten behavioral questions that are posed during a player's initial session.

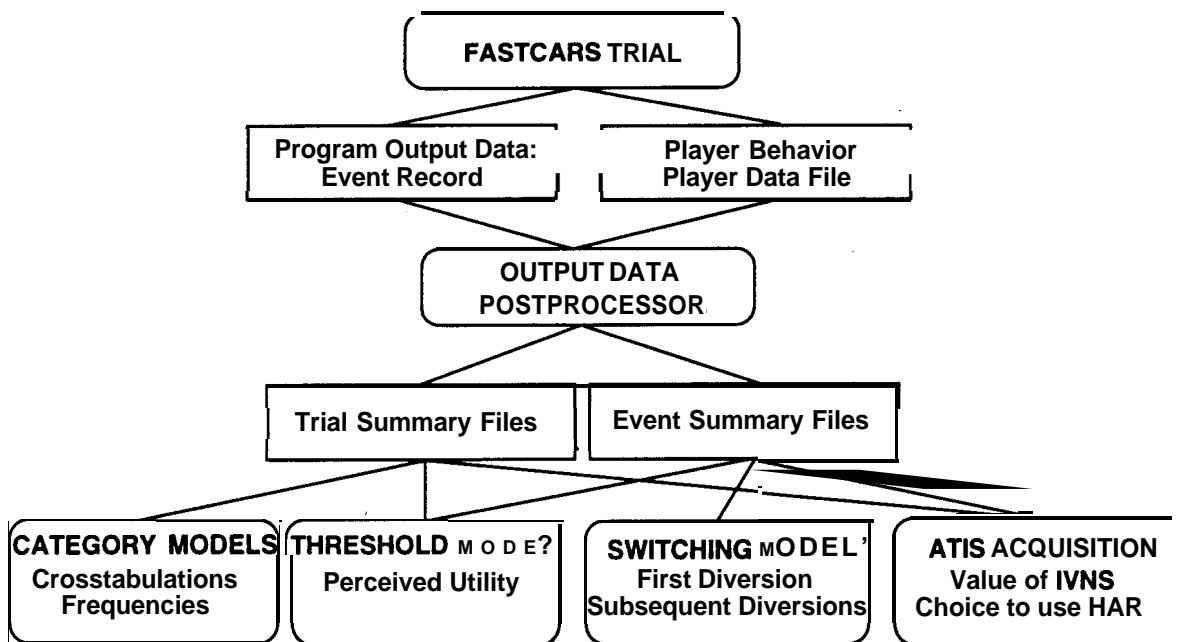
To perform various data analysis techniques, it was necessary to connect the player profile information with the trial and event data and to classify the data into a number of subset files. A special **FASTCARS** post-processor was developed to perform these tasks. Figure 6.1 illustrates the data reclassification process.

6.2.1 Trial Summary Files

The first output file generated by the post-processor is the 'trial summary'. This file contained a single record from each trial that summarized that trial's data, including player profile, in 30

variables. These variables include: Number of diversions in trial, player's level of experience, number of trials played by player, indicator of incidents generated during trial, player's gender and driving experience, responses to eight behavioral questions, initial route selected, total trip time and distance, schedule delay remaining at end of trip, number of road changes and stoplights encountered, average speed during trip, indicators for using VMS, HAR, IVNS, player's goal weights, penalty units accrued.

Figure 6.1 Data Analysis Process



6.2.2 Event Summary Files

Event summary **files** are created as composite records of the event data files and player profiles. For each event data file, the corresponding player profile data is added to the event records. Additionally, a set of new variables are calculated by the post-processing program and added to the event record. In total each event summary record has 67 variables, 30 described as in the trial summary and player profile and an additional 37 variables determined in the post-processor.

The additional variables help describe the state of the system at each event. These added variables include: average speed on current link, average speed on current path, average speed on current road, distance traveled on current path and current road, type of road coming from and turning to

(freeway or arterial), experience map level of links coming from and turning to, number of previous times links have been traveled, speed gradient (change in speed between links), and ratio of current average link speed to expected link speed. Additionally, at each event, the output program calculated the best utility path to the destination and recorded the values for the current path and the best alternative path. The actual score and normalized score for each of the five goals was calculated (20 variables) as was the projected current path score and the projected best alternative path score. For the best alternative path, the map level and previous times traversed was also calculated. The event data variables and their values are listed in Table 6.1.

Table 6.1 Event Data Variables

<u>Variable Name</u>	<u>Coded As</u>	<u>Meaning</u>
Divert	[0,1]	0 = No Divert, 1 = Diversion
Trials	[?]	Number of trials played
Userlvl	[1,2,3]	1 =Novice, 2=Intermediate, 3=Expert
Gender	[0,1]	0=Male, 1 =Female
Exper	[1-4]	Driving Experience
B1 - B8	[1-5]	8 behavioral questions rated 1 (strong disagree) to 5 (strong agree)
Asl	[Real]	Average speed on current link
Ast	[Real]	Average speed for trip
Asp	[Real]	Average speed for current path
A s r	[Real]	Average speed for current road
Rdchg	[Integer]	Number of road changes thus far
Evstop	[Integer]	Stop lights encountered thus far
Onfl	[Integer]	Previous times on from-link
Ontl	[Integer]	Previous times on to-link
Onatl	[Integer]	Previous times on best alternate to-link
Typefl	[0,1]	Road type of from-link @freeway, 1 =arterial)
Type tl	[0,1]	Road type of to-link
Typeatl	[0,1]	Road type of best alternate to-link
Mfl	[Real]	Userlvl/Map level of from-link
Mtl	[Real]	Userlvl/Map level of to-link
Matl	[Real]	Userlvl/Map level of best alternate-link
Numdiver	[Integer]	Number of diversions thus far
Enddist	[Real]	Shortest path distance to destination
Spdgrad	[Real]	Change in speed from last link
Spdratio	[Real]	Aslink / Link free flow speed
Curt-road	[Real]	Distance travelled on current road
HAR	[0,1]	0=OFF, 1=ON
IVNS	[0,1]	0=OFF, 1=ON
VMS	P- 41	0=no vms, 1 = no congestion, 2=minor congestion, 3=heavy congestion, 4=incident

6.3 Descriptive Statistics

The case study data set consisted of 108 trials performed by 27 participants. To summarize the data set, frequency tables were calculated on the trial level data. The results of these analyses are illustrated in Table 6.2.

Each player was assigned a userlevel upon starting a trial. Of the 108 trials, the distribution by userlevel was novice (40 trials - 37.0 %), intermediate (42 - 38.9%), and expert (26 - 24.1%). In 62 trials players diverted at least once; in 46 out of the 108 trials, no diversion was logged

Table 6.2 Trial Data Frequencies

FREQUENCY OF SCORES					
	<u>≤ 500</u>	<u>> 2500</u>	<u>> 5000</u>	<u>> 7500</u>	<u>> 9000</u>
COUNT	8	12	22	33	33
PERCENT	7.41	11.11	20.37	30.56	30.56
FREQUENCY OF HAR USAGE					
	<u>0 HAROFF</u>	<u>1 HARON</u>			
COUNT	70	38			
PERCENT	64.81	35.19			
FREQUENCY OF IVNS USAGE					
	<u>0 IVNSOFF</u>	<u>1 IVNSON</u>			
COUNT	89	19			
PERCENT	82.41	17.59			
FREQUENCY OF AT LEAST ONE DIVERSION					
	<u>0 DIVERT</u>	<u>>1 DIVERT</u>			
COUNT	46	62			
PERCENT	42.59	57.41			
FREQUENCY OF DIVERSIONS					
	<u>0 DIVERT</u>	<u>1 DIVERT</u>	<u>2 DIVERT</u>	<u>3+ DIVERT</u>	
COUNT	46	27	13	22	
PERCENT	42.59	25.00	12.04	20.37	
FREQUENCY OF USERLEVEL					
	<u>1 NOVICE</u>	<u>2 INTERMEDIATE</u>	<u>3 EXPERT</u>		
COUNT	40	42	26		
PERCENT	37.04	38.89	24.07		

TOTAL TRIALS = 108

6.4 Category Models

Crosstabulations are useful to determine if two variables are related. For the trial and event data collected from the case study, a series of crosstabulations was performed to measure the strength of association between variables. Associated with each table to be presented are several statistics that measure the extent of association between the data. Of main concern is whether or not the two variables being compared are dependent or independent of each other. A **chi-square** test of independence is useful to test the hypothesis that the row and column variables are independent. However, this test does not test for causality between the variables. The chi-square is based on the degrees of freedom in the table, defined as the number of cells in a table that can be arbitrarily filled when the row and column totals have been fixed, . For a **r(row) x c(column)** table there are $(r-1) \times (c-1)$ degrees of freedom. A high **chi-square** shows that there is increased likelihood that the row and column variables are not independent. Table 6.3 shows a listing for a two-tailed hypothesis for a chi-square distribution with **n** degrees of freedom at 95% confidence interval.

A second series of measures of association for ordered variables are based on comparisons between variable pairs. Cases are compared to determine whether they are concordant pairs '**P**' (both values of one pair are higher), discordant '**Q**' (one variable has a higher value, the second has a lower value) or tied (the two cases have one or both variables with equal value).

Tau-b measures the difference in concordant and discordant pairs. Where **T_x** is the number of pairs tied on variable x; **T_y** is the number of pairs tied on variable y.

$$\tau_b = \frac{P - Q}{\sqrt{((P+Q+T_x) + (P+Q+T_y))}} \quad (6.1)$$

Gamma reflects the probability that a random pair of observations is concordant minus the probability that the pair is discordant.

$$G = \frac{P - Q}{P + Q} \quad (6.2)$$

Somer's d added an asymmetric extension of gamma by accounting for **T_y**

$$D_s = \frac{P - Q}{P + Q + T_y} \quad (6.3)$$

For each of these statistical measures, higher values denote stronger linear association between the two variables.

Table 6.3 Chi-Square Hypothesis Testing at 95 % Confidence

Testing at 95% confidence interval with n degrees of freedom

<u>n</u>	<u>Chi-Square</u>	<u>n</u>	<u>Chi-Square</u>
1	3.841	6	12.592
2	5.991	7	14.067
3	7.815	8	15.507
4	9.488	9	16.919
5	11.070	10	18.307

The first set of crosstabulations performed examined the relationship between trial level data. Tables 6.4 and 6.5 illustrates analyses to show the strength of association between userlevel (familiarity with the network) and propensity to divert. This table shows that players with more experience were less likely to divert. One can suggest that more experienced players select better initial routes and develop a better sense of travel conditions, both factors contributing to fewer diversions. Comparing user-level to number of diversions, it is shown that expert players diverted less often; 21 out of 26 expert trials had 0 or 1 diversion. Alternatively among novices almost 50% of the trials had at least 2 diversions.

Table 6.4 Trial Category Analyses - Userlvl by Divert

		divert		
		0	1	ROW TOTAL
userlvl	1	13	27	40
	Novice	28.3	43.5	37.0
	2	20	22	42
	Medium	43.5	35.5	38.9
3	13	13	26	
Expert	28.3	21.0	24.1	
COLUMN TOTAL		46	62	108
		42.6	57.4	100.0

Gamma	-0.244186	Ordinal Measures of Association	
		Somer's d	-0.121196
		tau-b	-0.140117
		Chi-square(2 d.f.)	= 2.683771

Table 6.5 Trial Category Analyses - Userlvl by Number of Diversions

		numdiver				
		0	1	2	3+	ROW TOTAL
userlvl	COUNT 'COL PCT					
1	13	8	7	12	40	
Novice	28.3	29.6	53.8	54.5	37.0	
2	20	11	4	7	42	
Medium	43.5	40.7	30.8	31.8	38.9	
3	13	8	2	3	26	
Expert	28.3	29.6	15.4	13.6	24.1	
COLUMN	46	27	13	22	108	
TOTAL	42.6	25.0	12.0	20.4	100.0	

Ordinal Measures of Association
Gamma -0.271917 Somer's d -0.192025 tau-b -0.185543
Chi-square(6 d.f.) = 7.029812

Tables 6.6 and 6.7 comparing **userlevel by har** and **userlevel by ivns**, shows that drivers with higher userlevel are less likely to acquire additional information. Only 10.5% of all drivers using HAR were expert and out of the expert trips, only 4 out of 26 used HAR. Similarly, only 10.5% of all players using IVNS were expert level players and only 2 out of 26 experts used the in-vehicle navigator.

Table 6.6 Trial Category Analyses - Userlvl by Information

		har		
		HarOff	HarOn	ROW TOTAL
userlvl	COUNT 'COL PCT	0	1	
1	24	16	40	
Novice	34.3	42.1	37.0	
2	24	18	42	
Medium	34.3	47.4	38.9	
3	22	4	26	
Expert	31.4	10.5	24.1	
COLUMN	70	38	108	
TOTAL	64.8	35.2	100.0	

Ordinal Measures of Association
Gamma -0.289294 Somer's d -0.133263 tau-b -0.159531
Chi-square(2 d.f.) = 5.960479

Table 6.7 Trial Category Analyses - Userlvl by Information

		ivns		
		IvnsOff	IvnsOn	ROW
		0	1	TOTAL
userlvl	I COUNT COL PCT I			
	1	31	9	40
	Novice	34.8	47.4	37.0
	2	34	8	42
	Medium	38.2	42.1	38.9
	3	24	2	26
	Expert	27.0	10.5	24.1
	COLUMN	89	19	108
	TOTAL	82.4	17.6	100.0

Ordinal Measures of Association
 Gamma -0.307692 Somer's d -0.088143 tau-b -0.132340
 Chi-square(2 d.f.) = 2.483605

To examine the impact of acquiring information on the player's score, Table 6.8 lists a set of crosstabulations for player score by HAR and IVNS. There is a strong relationship between HAR and score indicating that players experiencing congestion and receiving lower scores were more likely to use HAR. Over 50% (22/42) players with scores below 5000 used HAR during the trial. There was less association for score versus IVNS. Generally players were aided by using HAR and IVNS as over 65% of HAR and over 68% of IVNS users scored over 5000.

Table 6.9 and 6.10 analyze the cross effects of VMS, HAR, and IVNS. It is seen that VMS is a trigger for gaining additional information. Over 30% of players receiving VMS messages of at least degree 2 turned on HAR. These were over 80% of all players using HAR during a trial. 15 out of 19 players using IVNS did so under conditions of VMS with messages of at least degree 2. It is striking to note that while IVNS was only used in 19 out of the 108 trials, HAR was used in all of these trials as well.

Table 6.8 Trial Category Analyses - Score by Information

		har			
score	I COUNT	HarOff	HarOn	ROW	
	I COL PCT I	0 I	1 I	TOTAL	
	0	2	6	8	
I sc<2500	I 2.9	I 15.8	I 7.4		
	1	5	7	12	
I sc>2500	I 7.1	I 18.4	I 11.1		
	2	13	9	22	
I SC>5000	I 18.6	I 23.7	I 20.4		
	3	20	13	33	
I SC>7500	I 28.6	I 34.2	I 30.6		
	4	30	3	33	
I sc>9000	I 42.9	I 7.9	I 30.6		
	COLUMN	70	38	108	
	TOTAL	64.8	35.2	100.0	

Gamma -0.574091 Ordinal Measures of Association
 Somer's d -0.280191 tau-b -0.360240
 Chi-square(4 d.f.) = 18.805878

		ivns			
score	I COUNT	IvnsOff	IvnsOn	ROW	
	I COL PCT I	0 I	1 I	TOTAL	
	0	5	3	8	
I sc<2500	I 5.6	I 15.8	I 7.4		
	1	9	3	12	
I sc>2500	I 10.1	I 15.8	I 11.1		
	2	16	6	22	
I sc>5000	I 18.0	I 31.6	I 20.4		
	3	28	5	33	
I sc>7500	I 31.5	I 26.3	I 30.6		
	4	31	2	33	
I sc>9000	I 34.8	I 10.5	I 30.6		
	COLUMN	89	19	108	
	TOTAL	82.4	17.6	100.0	

Gamma -0.459660 Ordinal Measures of Association
 Somer's d -0.141233 tau-b -0.227741
 Chi-square(4 d.f.) = 7.225741

Table 6.9 Trial Category Analyses - VMS by HAR

		har		
		HarOff	HarOn	ROW
		0	1	TOTAL
vms	0	1	1	2
	NoVms	1.4	2.6	1.9
	1	11	6	17
	Clear	15.7	15.8	15.7
	2	9	4	13
	Minor	12.9	10.5	12.0
	3	37	12	49
	Major	52.9	31.6	45.4
	4	12	15	27
	Incident	17.1	39.5	25.0
	COLUMN	70	38	108
	TOTAL	64.8	35.2	100.0

Ordinal Measures of Association
 Gamma 0.216762 Somer's d 0.103816 tau-b 0.127879
 Chi-square(4 d.f.) = 7.674363

Table 6.10 Trial Category Analyses - VMS and HAR by IVNS

		ivns		
		IvnsOff	IvnsOn	ROW
		0	1	TOTAL
vms	0	1	1	2
	NoVms	1.1	5.3	1.9
	1	14	3	17
	Clear	15.7	15.8	15.7
	2	11	2	13
	Minor	12.4	10.5	12.0
	3	44	5	49
Major	49.4	26.3	45.4	
4	19	8	27	
Incident	21.3	42.1	25.0	
COLUMN		89	19	108
TOTAL		82.4	17.6	100.0

Ordinal Measures of Association
 Gamma 0.153110 Somer's d 0.047572 tau-b 0.073494
 Chi-square(4 d.f.) = 6.036075

		ivns		
		IvnsOff	IvnsOn	ROW
		0	1	TOTAL
har	0	70	0	70
	HarOff	78.7	0.0	64.8
	1	19	19	38
HarOn	21.3	100.0	35.2	
COLUMN		89	19	108
TOTAL		82.4	17.6	100.0

Ordinal Measures of Association
 Gamma 1.000000 Somer's d 0.500000 tau-b 0.627103
 Chi-square(1 d.f.) = 42.471910

To test the strength of relationship between events and variables, a series of category analyses was performed on various subsets of the event data file. Crosstabulations were calculated for several event-variable pairs. The resulting correlation T-Scores are displayed in Table 6.11. The T-Scores are useful for determining whether a variable significantly contributes to the event. Generally T-Scores greater than 2.0 or less than -2.0 show a strong relationship between the variables. The sign of the value indicates a positive or negative relationship. For instance, negative T-Scores between **USERLVL** and **DIVERT** indicate that players with more experience were less likely to divert. Alternatively, the positive score between **VMS** and **HAR** indicate that players receiving information concerning worse congestion were more likely to turn on the HAR.

In this table, the rows list the event file variables and the columns list the events considered. The first column **DIVERT1**, was a file that contained all turning records from the start of a trial through the first diversion event. Similarly, **DIVERT2**, contained all turning records from the first diversion turn through the completion of a trial. Trials with no diversions were listed in **DIVERT1**. The final four analyses were performed from a data set including all turning and information search (turn on HAR, turn on IVNS, Look at Maps) events. Correlations were performed by event type for diversions, turning on HAR, turning on IVNS, and looking at the maps.

There were several important relationships identified from these analyses. The table clearly shows that several variables are significant factors in the diversion and information acquisition processes. **Userlvl** and **trials** showed to be significant for diversion and information acquisition. The negative signs on the t-values indicate that as a player's experience level increased, he was less likely to divert or seek information. It is hypothesized that more experienced drivers select better initial routes and have a better sense of travel conditions, both factors can attribute to fewer diversions. Similarly, better recognition of traffic conditions and network configurations reduce the need to rely on external information sources.

The ratio of **userlvl** to map level (**mfl**, **mtl**, **matl**) is a second indicator on network experience. Values greater than one are links on which a player's experience is greater than or equal to the maps provided. The t-values suggest that players with higher familiarity levels are more likely to divert to surface streets and less likely to acquire external information. Similar results are seen with **onfl**, **ontl**, and **onatl** indicating previous experiences on a link.

The type of road (**typefl**, **typetl**, **typeatl**) is notable for its influence on diversion. Drivers were more likely to divert to freeway links for first diversions **but** once on surface streets were as likely to stay on **surface** streets.

Table 6.11 Event Files Correlation T-Values

OBS	DIVERT1 1537	DIVERT2 893	DIVERT 2430	ALL-DIV 3394	HARON 3394	IVNSON 3394	MAPSC 3394
USERLVL	-1.38	-1.06	-2.30	-1.69	-2.69	-2.66	-3.73
TRIALS	-2.41	-3.02	-2.66	-0.12	-3.52	-3.57	-5.29
MFL	-0.21	5.30	5.55	-4.36	-1.39	-2.84	-4.70
MTL	8.40	6.88	11.54	-7.70	-1.50	-2.97	-4.98
MATL	-2.43	-2.86	-3.44	0.83	-2.02	-2.31	-1.42
ONFL	-2.00	-2.46	-3.92	-2.89	-2.74	-3.66	-4.56
ONTL	-6.07	-2.87	-6.64	-6.22	-3.17	-4.18	-5.70
ONATL	0.47	1.29	0.58	1.51	-1.50	-1.82	-3.78
TYPEFL	-2.05	3.20	1.13	0.05	-1.21	2.66	3.13
TYPETL	3.74	4.47	6.36	3.96	-1.79	1.83	1.49
TYPEATL	-3.41	-2.47	-4.07	0.37	-7.95	-9.66	-20.94
VMS	2.66	-2.17	0.44	1.21	2.09	0.21	-0.20
HAR	1.16	0.31	1.72	1.03	XXXXX	2.08	1.50
IVNS	1.38	-0.24	0.81	-0.44	2.83	XXXXX	-2.06
ASLINK	-7.41	-4.61	-8.61	-6.83	-2.36	-2.77	-3.73
ASPATH	-4.16	-2.75	-5.59	-3.31	-2.03	1.82	-2.49
ASROAD	-4.59	-3.03	-4.32	-4.13	-0.11	-0.57	-1.85
ASTRIP	-4.16	-0.78	-4.13	-3.41	-1.80	0.87	-5.29
NUMDIV	XXXXXX	9.53	16.78	16.59	-3.22	0.47	0.38
ENDDIST	0.57	3.00	0.47	2.48	2.41	2.62	0.67
SPDGRAD	0.48	-3.07	-2.11	-2.34	-1.29	-1.02	-0.42
SPDRATIO	-3.21	-4.65	-5.57	-4.50	-3.97	-3.22	-5.09
RDCHG	0.24	-2.82	2.53	2.68	-2.39	-0.03	-0.97
EVSTOP	1.87	0.84	3.95	4.36	-1.07	-0.14	-2.07
CURROAD	0.22	-1.90	-2.22	0.84	-0.98	-5.80	-6.14
B1	0.72	0.93	1.40	1.52	-0.51	-0.10	-0.67
B2	0.50	0.28	0.33	0.47	0.30	-2.70	1.84
B3	-1.13	-0.48	-1.75	-1.93	0.17	1.26	-0.64
B4	0.59	-0.22	0.56	0.55	1.79	-0.75	-0.04
B5	0.75	0.15	0.90	0.92	-0.95	-0.68	0.15
B6	-1.67	-0.17	-1.81	-1.58	1.93	-4.67	1.87
B7	-0.83	1.2	0.72	0.38	1.75	1.99	-6.24
B8	-0.23	-4.25	-3.50	-2.99	0.25	-4.59	-0.38
EXPER	1.81	2.04	2.22	2.94	-0.89	4.41	2.56

The availability of VMS also influenced diversion and information acquisition. Most notable is the significant t-value on **HARON**, suggesting that drivers receiving VMS information indicating congestion or incidents ahead may desire more information and will tune to HAR. The two active forms of real-time information acquisition (**har**, **ivns**) influenced each other's use. From the crosstabulations it was seen that all 19 players who used IVNS also used HAR during those trials. IVNS was never used alone in a trial; always in conjunction with HAR.

Average speeds are significant indicators to explain arousal and diversion behavior. Decreasing average speeds positively influenced diversion and information acquisition behavior. **Similar** results were seen with **spdratio** and **spdgrad**. Other relationships seen is that as the number of diversions increase, there is a greater likelihood of further diversions. In addition, diversion behavior may be impacted by the proximity to the destination. The positive t-value on **enddist** and **divert2** indicate less propensity to divert closer to the destination.

6.5 Enroute Switching Model

To predict diversion behavior, two **logit** models were developed. The first examines the factors that influence primary diversion and the second examines secondary diversions.

6.5.1 Logit Choice Model of First Diversions

The primary diversion event summary file was used to develop the binary choice model for **enroute** diversions. The primary diversion file included all turning movements prior to and including the first diversion record taken from the 108 event files. Trials with no diversions were included in this collection. This file contained nearly 1300 pre-diversion turning records.

Out of the 108 event files, 62 trials had at least one diversion. To formulate the data set for the analysis, the non diversion records were randomly sampled to create a reduced sample data set of approximately the same number of diversions and non-diversions. The result of the **logit** model estimation is shown in Table 6.12.

Eleven variables were found to be significant: Two speed-related variables **spdgrad**(speed gradient) and **aslink**(average speed on prior link) had negative coefficients indicating that as the speed decreased, players were more likely to divert. Four experience-dependent variables were also found to influence diversion: **Ontl**, **mfl**, **mtl**, and **mapatl**. The first three of these have negative coefficients suggesting that experience on the current path reduces the likelihood of primary diversion. This may be part of the threshold of conflict tolerance factor: Drivers with more experience are familiar with locations that have heavier congestion and are less likely to react. **Mapatl**, representing a level of experience on the alternate path, is a positive coefficient suggesting that players are more apt to divert to a street on which they have a higher level of experience. **Typefl** has a negative value and indicates that drivers are less likely to divert away from freeway links.

Real-time information acquisition was also found to influence behavior. A positive value for **VMS** indicates that players react to messages that indicate congestion ahead. **HAR** has a negative value suggesting that it impeded diversion behavior. This may be explained as drivers seeking information under uncertainty, not knowing the severity of congestion. When congestion is not severe on the current route, or more severe on alternate paths, the driver is more likely to continue on the same path.

The number of road changes, **rdchg**, is a negative factor on diversion. This seems to indicate that drivers who make many road changes have more complex travel plans and are less likely to divert. The last variable influencing diversion was **enddist** (shortest path distance to destination). It is interpreted that players are less likely to divert the closer they are to their destination.

Table 6.12 Logit estimation for Primary Diversion

```

***** LOGIT ESTIMATION *****
Dependent variable: divert

Value      Label      count      Percent
  0         NoDivert    51         45.13
  1         Divert     62         54.87

Independent      Estimated      Standard      t-
Variable          Coefficient   Error          Statistic
  one              7.64050       2.39982        3.18378
  aslink          -0.10714      3.12952e-002  -3.42348
  spdgrad        -0.51177      0.40930       -1.25037
  ontl           -0.97869      0.33201       -2.94779
  mfl            -0.98021      0.65795       -1.48980
  mtl            -3.52558      1.29046       -2.73204
  matl           4.39821      1.45893        3.01467
  typefl        -4.14542      1.39648       -2.96848
  vms            0.59779      0.32097        1.86241
  har           -1.96724      0.91144       -2.15840
  rdchg         -0.38355      0.30490       -1.25795
  enddist       -2.71195e-002 5.29754e-002  -0.51193

auxiliary statistics      at convergence      initial
log likelihood            -35.02472           -78.32563
number of observations          113
percent correctly predicted    85.84071
    
```

6.5.2 Logit Choice Model of Subsequent Diversions

It was hypothesized that once diversion has occurred, resulting behavior, including secondary diversions, would be influenced by different factors. A second set of **logit** models were calculated using the secondary diversion file. The data variables for this set was identical to those from the primary diversion file. These records included all events that took place after primary diversion points. In **this** tile there were 1000 total records, 84 of which were secondary diversions. Records were randomly sampled to create a data set of roughly equal proportion of diversions to non-diversions. The result of this **logit** model estimation is shown in Table 6.13.

Similar results to the primary diversion model were found with some notable exceptions. **Numdiver** (number of diversions) became significant. The more a player diverts, the more likely one is to divert again. Having additional information was not significant for secondary routing. One explanation is that diversions take drivers to surface streets where VMS and HAR are less useful. Additionally, for this model, **enddist** has a positive sign. This suggests that players are more likely to have several diversions further away from the destination.

Table 6.13 Logit estimation for Secondary Diversion

```

***** LOGIT ESTIMATION *****
Dependent variable: divert

Value      Label      Count      Percent
  0      NoDivert      78      48.15
  1      Divert      84      51.85

Independent Variable      Estimated Coefficient      Standard Error      t-Statistic

one      7.32636e-002      1.19476      6.13209e-002
mtl      -3.73263      0.91309      -4.08793
matl      3.71311      0.93037      3.99101
numdiver      1.66923      0.30358      5.49849
enddist      8.15365e-002      4.56766e-002      1.78508
aslink      -3.23108e-002      1.80283e-002      -1.79223
rdchg      -0.76728      0.17492      -4.38652

auxiliary statistics      at convergence      initial
log likelihood      -53.82411      -112.28984
number of observations      162
percent correctly predicted      65.18519
    
```

6.6 Value of Information Acquisition Model

To study the potential benefits of in-vehicle navigation, a set of analyses were performed to examine potential changes in player score if each player had in fact used the IVNS for the entire trip. For each trip the link file and incident files loaded to the simulator are known. For each incident file (ten overall), a trial was conducted in which the IVNS was turned on at the start and remained on during the entire trial. The routing instructions suggested by the IVNS were followed and a set of values for the five goals was calculated.

For each trial played, the player's goal weights were matched to the corresponding incident file used to calculate a score that the player would have received had the IVNS been used. A new total score was calculated that represented an updated score aided by the IVNS. These scores were compared to the actual scores to determine benefits to players had the IVNS been used for the entire trip.

To measure the costs associated with using IVNS, various penalty units for initially turning on the IVNS and a per minute metered penalty were assessed. These values were compared to the actual player scores. The results are shown in Table 6.14. This table lists the average improvement in score for the entire set of trials as well as the number of improvements and declines in score. As the penalty assessments are varied there are changes in the potential benefits.

Each table displays scores calculated for several categories of drivers. Six categories were used for this analysis. The first, **ALL**, is for all players who participated in the case study. The second and third columns, **IVNS** and **HAR**, were those players who used either IVNS or HAR during their trip. The latter three categories were taken by the userlevels (1=**novice**, 2=**intermediate**, and 3=**expert**) assigned to the players during the case study.

The first table was tabulated using the penalty values applied during the case study: 200 points for turning on the IVNS and 25 points for each minute the IVNS was running. The second table was calculated using no penalty units. These tables illustrate that with no penalty assessed there are many more drivers that benefit and a higher overall average. As penalty units increase there are fewer improvements but the average improvement increases.

The results suggest that under conflict situations (non-recurring incidents, special event traffic) IVNS would be useful for rerouting individual drivers and improving goal achievement and increasing total scores. Under normal non-conflict conditions, drivers traveling on optimal paths may not benefit from IVNS. Generally, lower scores (under 8000) benefited most from IVNS.

Table 6.14 Value of Using IVNS
**IVNS PENALTIES
TURN ON 200.0 / PER MINUTE 25.0**

	ALL	IVNS	HAR	NOVICE	INTER.	EXPERT
Total Trials	108	19	38	40	42	26
Score-No IVNS	7242.45	6123.10	5944.45	6415.22	7413.01	8239.58
Score-IVNS	8215.77	8210.42	8196.36	8079.98	8201.10	8448.38
Ave Improve	973.32	2087.32	2251.91	1664.76	788.09	208.80
Num Improve	51	13	27	24	18	9
Ave Improve	3037.38	3370.44	3408.71	325 1.99	3212.61	2114.63
Num Declines	57	6	11	16	24	17
Ave. Declines	-873.46	-692.78	-587.5 1	-7 16.08	-1030.29	-800.17

**IVNS PENALTIES
TURN ON 0.0 / PER MINUTE 0.0**

	ALL	IVNS	HAR	NOVICE	INTER.	EXPERT
Total Trials	108	1 9	38	40	42	26
Score-No IVNS	7242.45	6123.10	5944.45	6415.22	7413.01	8239.58
Score-IVNS	9310.47	9294.19	9285.71	9182.51	9301.06	9522.52
Ave Improve	2068.02	3171.09	3341.26	2767.29	1888.06	1282.93
Num Improve	92	18	37	37	33	22
Ave Improve	2482.28	3387.05	3021.56	3021.56	2486.79	1568.54
Num Declines	16	1	1	3	9	4
Ave. Declines	-3 13.97	-716.13	-368.73	-368.73	-307.30	-287.90

KEY TO COLUMN HEADERS

ALL	=	All Players
IVNS	=	Players using IVNS During Trip
HAR	=	Players using HAR during Trip
NOVICE	=	Players with Userlevel = 1
INTER	=	Players with Userlevel = 2
EXPERT	=	Players with Userlevel = 3

6.7 Summary

This chapter presented the data analyses performed. Several techniques were used to inspect the data and model driver behavior. Frequencies and category models illustrated relationships and associations between variables and observed driver behavior. The **logit** models described factors impacting primary and secondary diversions.

From the analyses it was clear that several indicators trigger arousal and motivation to change behavior. Drivers' prior experience with network layout and conditions affects current perception of travel conditions. Knowledge of alternate routes influences diversion behavior. Travel speeds and changes in speeds are significant predictors of arousal. Real time information acquisition, passively with VMS and actively with HAR and IVNS, do improve driver perception and decision making ability.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Perspectives

This research presents a new theoretical formulation and data collection approach for analyzing **enroute** driver behavior and the potential impacts of real-time traffic condition information. Researchers have been trying for several years to develop better dynamic models of driver behavior. The complexities of human nature and the large number of factors that influence the driving and travel decision process have made this problem challenging. The recent development of **ATIS** technologies has intensified the need for better models and has resulted in many research efforts.

The proposed theoretical formulation, based on conflict theory and goal attainment, is not a new concept. Theories of human behavioral choice have been used to describe decision processing in several areas including psychology and consumer behavior. The inherent structure of travel choice, including initial route choice, goal formulation, and **enroute** adjustment seem well suited to an approach based on conflict theory. Concepts of conflict threshold and information acquisition are well modeled in this formulation.

The ability to use in-laboratory experimentation to test behavioral theories is important to the state-of-the-art. **FASTCARS** is a sophisticated program that runs on a relatively simple platform. Unlike interactive video-based simulations requiring hundred of thousands of dollars in imaging technology and advanced computers, **FASTCARS** requires, at a minimum, a **386/33** MHz computer with VGA graphics and a sound board. A personal computer of this type equipped with maximum amenities, may be purchased for under \$2000. With the advent of laptop computers, **FASTCARS** is an easily portable system that does not require a static laboratory for experimentation. Alternatively, the entire program can be transported on a box of diskettes or on a portable hard drive and recreated on any computer that meets the basic specifications. For its price and performance, **FASTCARS** worked reasonably well in the case study described earlier. Players indicated that the game was a realistic simulation of travel behavior and choice.

7.2 Public Policy Issues

The significance of this research project lies in the theoretical formulation, implementation of the theory, and the relevance of the results of the case study. The first two have been well documented throughout this report. The latter deserves attention as well.

Although the test case was a special event trip, it is likely that other types of trip could have been substituted. The results on diversion behavior and information acquisition,

described in the previous chapter, are not surprising but **confirm** many basic hypotheses of travel behavior and the potential impact of **ATIS**.

It is clear that driver familiarity with network conditions and layout and perceived traffic conditions are key components in predicting trip making success. The least experienced driver traversing a route under free flow conditions and known to lead directly to the destination should be expected to perform well. **Enroute** assistance of **ATIS** will not have a great impact on this trip because there is limited uncertainty and anxiety. Similarly, drivers who are used to experiencing traffic congestion on a section of roadway are less likely to panic and divert or acquire information. Such phenomena is observed daily in every major city where commuters routinely sit on congested freeways. After making several trips, commuters become more accustomed to travel conditions and adjust their tolerance to conflict levels based on expected travel conditions and desired travel objectives. There are levels of recurring congestion that are expected and commuters realize that neither diverting nor acquiring information will be of use. In some cases, commuters do not have access to alternate freeways and would be worse off diverting to surface streets.

It seems that somewhere between these extreme cases, **ATIS** can be useful to assist drivers with route guidance and perceiving travel conditions. Drivers with less experience perceiving travel conditions may use **ATIS** systems to clarify the state of congestion on their current path. Drivers with less experience with network layout may find route guidance information useful for identifying alternate paths. Generally, as drivers become more familiar with travel conditions and alternate paths, **ATIS** may become less useful for them under recurrent travel conditions. Conversely, more experienced drivers may benefit more from using **ATIS** and acquiring information during pre-trip planning. This is an area that should be addressed in further study.

Other major policy issues impacting **ATIS** research and development involve pricing and implementation strategies. How much should **ATIS** technologies cost and how many drivers should be equipped with them. Questions of information content and media presentation are also vital to ensuring the maximum benefit is experienced. These issues were beyond the scope of this research but are being addressed by others.

7.3 Future Research

Beyond the limits of this research, there is much room for expansion. The theoretical formation is a basis for studying driving behavior but the development is incomplete. More attention needs to be paid to the **pre-trip** planning aspects and its relationship to **enroute** behavior. Further research should expand the formulation and focus on post-trip evaluation and the dynamic of day-to-day adjustments. Short and long term evolution in behavior are impacted by cognitive processing and psychological issues, such as memory, learning, and cognitive recognition. Better understanding of these issues are necessary to form the complete circuit and model dynamic behavior.

Long term studies of information acquisition are necessary to judge the impact of real-time information on behavior. Information seems to improve short term decision making but its longer term effect on shaping driver behavior is not well documented. Similarly, long term studies to document the impact of audio versus visual or combined technologies on behavior needs to be explored.

Preliminary case studies show the **FASTCARS** is a useful tool. There are several improvements that can be made to improve its applicability. First, a more in-depth pre-trip planning module should be considered. The relationship between departure time, initial route choice, and goal attainment is crucial. It is known that experience and past performance influence departure time and initial route choices. Currently, **FASTCARS** does not allow players to acquire information pre-trip. Adding this ability to the simulator would greatly improve its utility and value for future case studies.. Improvements in the user interface will also add to the program's versatility. The network viewer could be aided by a 'windshield display rather than the current birds-eye' display. Similarly, interactive graphical maps that show current location would be a nice addition to the in-vehicle navigation system and PCX maps currently in place.

There are endless revisions and improvements that one can make to computer programs, especially simulations. For the purposes of research, the best improvements are those that better represent the theories being tested. Sometimes, more bells and whistles' can distract a user's attention and detract from the real purpose of the simulator. Complexity is not always proportional to effectiveness. It would be interesting to evaluate **FASTCARS** along side other simulation programs to evaluate their abilities to replicate the driving process and collect data.

7.4 TestBed Application - Anaheim, CA

Special event traffic management is of special concern to many cities around the United States and world wide. Traffic attracted to and generated by special event sites contributes to the non-recurrent traffic problems faced by many cities. The revenues generated by special event attractors are of major significance to communities. It is important to maintain support for these venues by encouraging patronage, managing traffic to and from these sites, and limiting the impact on the surrounding travel networks. **ATIS** technologies have great potential to improve traffic flow around special event attractors and there are several cities currently developing and testing such systems.

As such, it is contended that **FASTCARS** and the research approach posed in this project would be useful for integration into the ATMS **Testbed** Research Program being conducted around the city of Anaheim. Anaheim is a leading city in its determination to implement a large-scale traffic management system, complete with **ATIS** technologies, to improve traffic flow. There are plans to install VMS and HAR systems in the city to assist in directing traffic to venues and parking facilities. In addition the availability of other

technologies such as videotext and in-vehicle navigation systems is seen as potentially useful tools for further aiding drivers.

Anaheim currently is home to Disneyland, a convention center, and Anaheim Stadium (home Major League Baseball's California Angels and National Football League Los Angeles Rams) among others. Furthermore, a **20,000** seat arena is now under construction adjacent to the Stadium. Routing traffic to and from these major attractors is of **special** concern to the City of Anaheim and other cities of the like. Much of the traffic stems from infrequent patrons who come to the city for these special events. There are drivers with varying degrees of familiarity with the city layout and the traffic network.

The information gathered in this research would provide support for many of the programs being conducted in the **Testbed** project. The results on driver behavior would assist the development of the proposed simulator to predict dynamic response as well as serve to bolster the efforts in real-time provision of traveler information. Further adjustments to **FASTCARS** can be made to undertake additional studies to determine the effectiveness of providing real-time information for pre-trip planning.

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