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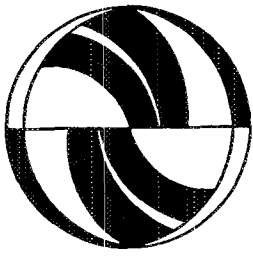https://escholarship.org/uc/item/81x1384q

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IN-LABORATORY EXPERIMENTS TO INVESTIGATE DRIVER BEHAVIOR UNDER ADVANCED TRAVELER INFORMATION SYSTEMS

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ABSTRACT

In-laboratory experimentation with interactive microcomputer simulation is a useful tool for studying the dynamics of driver behavior in response to advanced traveler information systems. Limited real-world implementation of these information systems has made it difficult to observe and study how drivers seek, acquire, process, and respond to real-time information. This paper describes the design and preliminary testing of an interactive microcomputer-based animated simulator, developed at the University of California, Irvine, to model pre-trip and enroute driver travel choices in the presence of advanced traveler information systems. The advantages of this simulator are realized in its versatility to model driver decision processing while presenting a realistic representation of the travel choice domain. Results from a case study revealed that increased driver familiarity with travel conditions and network layout reduces driver reliance on information systems and influences drivers diversion behavior.

INTRODUCTION

Advanced Traveler Information Systems (ATIS) are an integral component of Intelligent Vehicle/Highway Systems (IVHS) research and development. Deployment of ATIS technologies and provision of real-time information will lead to more efficient distribution of travelers to routes producing an improvement in system performance. An essential purpose of ATIS deployment is to create communication links between drivers and traffic control centers. It is believed that wide spread broadcast of real-time traffic condition and route guidance information can have a major impact on driver behavior, network performance, and travel safety, since, real-time information can improve drivers' perception of travel conditions and assist drivers with pre-trip and enroute travel choices.

To study the impacts of ATIS on driver behavior, non-traditional data collection techniques are needed. Limited real-world implementation of ATIS technologies has made it difficult to directly observe travelers' responses to real-time information and evaluate changes in driver behavior. Moreover, it would be difficult to develop revealed preference techniques to ask drivers about travel under ATIS since few drivers have ever used or are aware of ATIS technologies. Stated preference survey techniques, while useful for static choice sets under scenarios that are well defined, become less reliable when trying to capture the dynamics of travel choice and processes that are activated in real-time. Enroute travel choices, often made in real-time as a response to sudden changes in network conditions, reflect drivers' cognitive and psychological processing abilities that are also temporally and spatially dependent. Another concern about stated preference techniques is that it is not uncommon for people to respond differently from what their real-world behavior would be.

The process of seeking information is a critical element of human behavior and, as such, should be a primary focus of driver behavior research. Fundamental theories of psychology and human behavioral choice focus on the need for people to acquire information to help identify and solve problems. It has been posed that people seek to acquire information when current

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perception and memory are inadequate for prediction or evaluation needs. Models of information acquisition aim to analyze under what conditions individuals 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. Limitations in people's cognitive abilities restrict their ability to process and store information. As such it has been suggested 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 that it is presented (Hogarth, 1987).

BACKGROUND

In-laboratory experimentation with interactive simulation has become a popular tool for collecting data. In light of the limited deployment of ATIS technologies and the necessity to study the dynamics of travel choice under ATIS, simulation is gaining wide acceptance as a data collection technique. While it is recognized that in-laboratory experimentation does not always obviate the need for field testing, interactive simulation does provide a low cost, highly portable method for testing specific issues of behavioral concern that are difficult to captured with survey techniques or cannot be adequately observed in the real-world. For driver behavior research, simulation provides a platform for collecting revealed preference data within scenarios that cannot be well presented in survey form.

In the past few years several microcomputer-based interactive simulators have been developed to study the dynamics of driver behavior and provision of real-time information. IGOR, Interactive Guidance on Routes (Bonsall and Parry, 1991) was created for assessing driver's compliance with route guidance advice. IGOR simulates enroute travel through a network and emulates an in-vehicle navigation system to provide players with real-time route guidance. The quality of advice is varied from very good to bad and enroute decisions are analyzed to determine the rate of advice acceptance as functions of advice quality, previous experience with advice, network familiarity, and personal driver characteristics.

In IGOR, enroute travel is simulated on an intersection by intersection basis. At an intersection, players are required to press a key to indicate the next link to traverse. The simulation then skips to the next intersection to be encountered. Travel between intersections is simulated by 'engine sounds' of varied duration and pitch that are proportional to the time required to traverse the link and the link travel speed; higher pitched sounds correspond to less congested and higher speed links. At each decision point decision and network-related data are recorded to files to be later combined with answers obtained from pre and post-session surveys.

Researchers at MIT developed an interactive simulator to facilitate data collection and calibration of a route choice model based on fuzzy set theory, fuzzy control, and approximate reasoning (Koutsopoulos et al., 1993). This program is loosely modeled after IGOR but has capabilities that are dramatically improved from IGOR's primitive display. Effort was made to enhance the user interface, allow for modeling different operating conditions, improve the information provision capabilities, and to account for the driving task. The visual display graphically represents the driving experience with a car moving through a network. Information is presented through a simulated Roadside display/broad casting system as well as a graphical in-vehicle information window. A case study was performed in which traffic scenarios were randomly generated for three parameters: congestion, accidents, and information availability. Data was used to calibrate a model of approximate reasoning.

Chen and Mahmassani (1993) describe development of a simulator that integrates a traffic simulation program and offers the capability for multiple driver participants. This simulator models pre-trip planning, enroute travel, and post-trip evaluation. In the pre-trip planning phase participants are asked to select a target earliest departure time and a target path. At the specified departure time, players are shown a map of the network displaying expected trip times for each route; players control whether to depart on-time or to delay the start of the trip. At the departure time, players select their initial route.

The enroute display of this simulator has three components: a network illustrator, legend window for explaining color codings, and real-time message display. During enroute travel

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players receive real-time updates of the vehicle's position. At nodes where route-switching is possible, players decide whether to continue on the current route or divert to alternate paths. The post-trip module provides players with a map of the network that highlights the path taken. Summary statistics on the decisions made during travel are also provided to the player. Players are asked to then input new starting parameters (target earliest departure time and target route) for the next day's trip.

Each of these simulators address key aspect of the problem domain: the IGOR effort investigated compliance with route guidance, the MIT effort explored fuzzy set theories, and the Texas effort is investigating day-to-day adjustments. However, with respect to information display and acquisition, each of the aforementioned simulators are similar in nature. First, each effort simulates only the provision of visual information. Second, each simulator does not allow the participant to actively seek information; the ATIS systems are controlled variables in the experiments.

It is clear that real-world implementation of ATIS will involve multiple media formats, audible and visual, as well as varied message contents, route guidance and traffic condition information. Furthermore, some information may be posted road side and be passively available to all drivers with limited effort to acquire (i.e., variable message signs - VMS). Other information may be available to most drivers but will require active acquisition (i.e., highway advisory radio - HAR). Most autos are equipped with radios but drivers have to actively tune in to stations carrying traffic information. Still other information may be available to a subset of drivers who will pay extra for this service but will also actively decide when to acquire it (i.e. in-vehicle navigation systems - IVNS). The style of presentation and message content is expected to have a large effect on drivers' willingness to use ATIS.

In response to the need to study active information acquisition and the effects of media format and content, a theoretical model of driver behavior under ATIS based on conflict theory was proposed (Adler et al., 1993). It was further proposed that interactive simulation be used to test the theory and study active information acquisition. This paper describes the development

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and implementation of FASTCARS (Freeway and Arterial Street Traffic Conflict Arousal and Resolution Simulator), the interactive microcomputer-based driving simulator developed at the University of California, Irvine that simulates pre-trip and enroute travel decision making in a real-time environment. To study the impacts of ATIS on behavior, FASTCARS emulates three major types of ATIS technologies: variable message signs (VMS), highway advisory radio (HAR), and in-vehicle navigation systems (IVNS).

SIMULATING DRIVING BEHAVIOR

Vehicular travel decision making is characterized by three phases, pre-trip planning, enroute assessment and adjustment, and post-trip evaluation. Pre-trip planning refers to the series of decisions made before embarking: selection of trip purpose, travel objectives, destination, departure and desired arrival times, and initial route choice. The enroute assessment and adjustment process details the travel experience between origin and destination. Assessment refers to the process of perceiving travel conditions and evaluating travel progress. Adjustment describes the process of making changes to the initial travel pattern as established during pre-trip planning. Enroute adjustments include route diversion, changes to activity patterns, and revision of travel objectives. During post-trip evaluation, drivers update their knowledge pertaining to the travel system based on information gathered from the trip just completed and compared with prior experiences. This updated perception will influence the pre-trip planning decisions for future trips.

Pre-trip and enroute travel choice is influenced by drivers' perceptions of travel conditions and degree of spatial network knowledge. In an ideal world, drivers might have perfect information on travel conditions and network path options and therefore be better able to select more efficient route choices. In reality, drivers' perceptions of network conditions or spatial knowledge are imperfect, thus, drivers often have some degree of uncertainty when determining travel choice strategies. Higher levels of imperfect information and uncertainty are more likely to

result in less efficient travel choices. Drivers' decision making may be enhanced through the acquisition of real-time traffic condition or route guidance information. Providing drivers with real-time information about current network conditions can decrease uncertainty, improve perception, and result in more efficient travel behavior.

DEVELOPMENT OF FASTCARS

FASTCARS was designed to be a flexible and portable data collection tool. It runs on a single personal computer and requires a 386 /25 MHz or higher machine equipped with VGA graphics. Without HAR files, the program takes less than 3 MB of hard disk space. A voice adapter and extra hard disk space is needed for the HAR system. Figure 1 illustrates the hardware setup used for FASTCARS.

FASTCARS was designed to effectively model rational pre-trip planning and enroute decision behavior. It is a simulation of travel decision making rather than a simulation of human factors or driving ability. While there are many factors that influence driving behavior in real-time, it is impossible to capture and simulate these in-laboratory. The case study to be documented in this paper was constructed as a controlled environment. FASTCARS was programmed to represent travel conditions consisting of a single driver traveling in network flow without worrying about safety implications. In addition, to focus on active behavioral choice rather than personal interpretation, perfect information and data was presented to players.

Before discussing the application, the following sections briefly describe FASTCARS including the general system architecture, the pre-trip and enroute modules, and the data inputs and outputs. For a fuller description of FASTCARS, please refer to Adler et al., (1992, 1993).

MODELING PRE-TRIP PLANNING

Each FASTCARS session begins with a login sequence. For player identification and data storage purposes, participants are first asked to enter both a four-digit identification code as well

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as their name. The four-digit code is used for naming the output files resulting from the session and the identification check insures that each player is assigned a unique id code. After this login sequence, the pre-trip phase is initiated.

During pre-trip planning, drivers make a series of choices that characterize the travel process. Based on the desired activity, drivers select a destination, departure time, desired arrival time, an initial route, and a series of travel objectives. Each of these choices is captured in FASTCARS' pre-trip planning module as depicted in Figure 2. For data collection and experiment control purposes however, FASTCARS can be programmed so that any or all of the pre-trip choices may be preset by the administrator or available for the participants to select.

Scoring and Evaluation

Players are evaluated on their ability to maximize their travel score. The scoring system incorporated into FASTCARS is based on a linear additive weighted utility function of travel objectives. A set of travel objectives to be used in the game are presented to players during pre-trip planning. To capture variations in personal preference, players are given the opportunity to distribute a total of 100 scalar weights among the goal set. At the conclusion of the session the weights are multiplied by the values realized for each travel objective and summed over the goal set for a maximum possible score of 10,000 points. Score is one of the case study variables used to compare travel behavior among the participants.

The scoring function for each objective is predefined in FASTCARS and at the end of the simulation, each goal is normalized to a score between 0 and 100 by its own logistic normalization function. The shape of these normalization curves are estimated from preset ideal and minimum acceptable levels of goal attainment. 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. For example, consider the typical travel goal 'minimizing travel time'. For a trip with an expected travel time of 45 minutes, levels for ideal and minimum acceptable scores

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might be 35 minutes-95 score and 60 minutes-30 score respectively. A corresponding logistic normalization curve is estimated and applied in FASTCARS.

MODELING ENROUTE TRAVEL BEHAVIOR

In the enroute travel module, FASTCARS emphasizes the real-time decision making procedures over the actual driving process. Figure 3 illustrates the iterative enroute travel process. FASTCARS presents a user interface that simulates a bird's eye view of link-by-link travel. The animation is used to generate an environment that can capture the various temporal and spatial elements that influence enroute behavior. Figure 4 illustrates the basic user interface for enroute travel. This display has four components: the network viewer, the control panel, road-side information viewer, and the in-vehicle navigator.

During enroute travel, players aim to navigate their vehicle through the network to the destination. There are six primary actions that players may undertake: (1) lane changing, (2) road changing, (3) viewing network maps, (4) revise travel objectives, (5) acquire HAR information, and (6) acquire navigation information through the IVNS. The following sections describe the enroute user interface and the player actions.

Network Viewer

The largest section of the interface is the network viewer. Travel along a one-mile stretch of roadway is simulated. The player's vehicle, or cursor, is displayed as a solid rectangle; other vehicles are shown as 'fuzzy rectangles'. To enhance the perception of travel conditions, several properties were integrated. Links can contain multiple lanes and network traffic for two-way roads flows in both directions. Travel speeds vary by lane and left-most lanes generally have higher travel speeds. Link volumes are inversely proportional to travel speed. Surface streets are distinguishable from freeways by the addition of traffic signals and generally lower speeds.

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Signals have set timings and on the red cycle, cars caught behind the stop line will queue and wait for the green cycle. In all, FASTCARS presents a realistic simulation of network travel.

Players control lane and road changing behavior; both are initiated with single key strokes. When a lane change is signaled, the cursor changes to an arrow that points to the direction of the road change. A lane-switch delay, inversely proportional to the current travel speed, initiates a small lag before the lane transaction is carried out. At higher speeds, less time is needed to complete a lane change.

Intersections are displayed by a double line crossing the current link section. Arrows on either end of the cross street indicate available turning movements. Players wanting to initiate a road change must enter the correct key stroke and have their cursor in the correct lane. All turns from freeway links are made from the rightmost lane; on surface streets, left turns are made from the left-most lane and right turns from the right-most lane. An impending road change is depicted in the display by a change in color of the cross street and blinking of the arrow indicating the direction of the road change. When the cursor enters the intersection, FASTCARS automatically guides the cursor through the turn. If the cursor is not in the correct lane, the turn will not be executed.

Control Panel

The control panel, on the lower left of the window, 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.

Emulating ATIS

FASTCARS is equipped to simulate variable message signs (VMS), highway advisory radio (HAR), and in-vehicle shortest time navigation system (IVNS). The upper left-hand window in the user interface depicts any VMS and other road-side passive information signage

including 'next exit' displays. The upper right-hand window is the IVNS display. HAR is emulated with the assistance of a voice adapter and external speakers.

VMS is used to display traffic condition information on the current road. A search heuristic is employed to scan downstream for incidents or traffic congestion. Based on the results of the search, one of four VMS message categories is displayed : "Road Clear", "Minor Congestion", "Major Congestion", or "Incident Ahead".

The FASTCARS IVNS presents drivers with shortest time path route guidance information. At each node, the IVNS uses a shortest time path algorithm to find the shortest time path to the destination. The results of this search are displayed in three phases in the window. At the bottom of the window, the player is informed of the predicted minimum time and distance to the destination on the shortest time path. The top portion of the window graphically and textually describes the next action needed should the driver choose to follow the route guidance advice. An arrow is used to indicate to the player which direction to follow at the next intersection. A textual description of the next road change informs players of the direction of the shortest path.

HAR is implemented through a voice adapter that plays 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 profiles, a series of HAR files can be prepared and linked to the incident files. Both the incident and HAR files are inputs to the program, accessed at the start of the simulation.

Network Representation

The central element of FASTCARS is its ability to simulate travel along a traffic network and to represent basic travel characteristics, such as variations in travel speed, lane changing, and road changing involving both freeway and arterial street networks. Additionally, the program was

designed to model temporal factors that impact travel choice, including delays caused by congestion, and incidents, and traffic signals.

Travel networks needed for FASTCARS are developed from three basic components: 'links', 'streets', and 'intersections'. 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 or nodes. A series of links are combined to form a street. FASTCARS networks are coded and stored in two ASCII text data files a 'street' data file and 'link' data file. 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. The 'link' data file stores various link-specific characteristics including expected speeds, number of lanes, and presence of variable message signs.

Representing Incidents

FASTCARS simulates freeway incidents in real-time. Freeways are generated probabalistically and stored in separate data files external to the FASTCARS program. There are two reasons for generating the incidents outside the simulator. First, having a set of known incident files provides better control over experiment design. By generating a limited number of incident files, researchers are able to develop a set of experiments in which players are subjected to identical travel conditions. Second, to facilitate HAR emulation as currently performed by FASTCARS, it is necessary to have preset incident files. Based on known incident files, a series of HAR messages are prerecorded and assigned to specific incident events. It would be possible, however, to have FASTCARS directly simulate incidents without needing external file storage.

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 data file and generate incident files. The link data file is accessed and incidents are randomly generated and stored into files. A

simple algorithm is used to generate each incident. For each link in the link data file, a random number is generated. If this number is less than or equal to the incident probability listed in the file, a new incident is created. Each incident is then assigned four parameters: starting time, severity, duration, and link speed.

In FASTCARS, the records contained in the incident data file are read into memory and stored in a queue. At each time interval, the clock time of the simulation is compared to the lead incident on the queue. If the times are equal, the incident is processed and removed from the queue.

Incidents are modeled in FASTCARS, as either being generated during the simulation or existing on the network as the simulation begins. The starting time is calculated by randomly generating a number based on a uniform probability between 0 and 3600 (60 minutes). This number is then subtracted by 900 (15 minutes) to generate a starting time between -900 (15 minutes before commencement of a trip), and +2700 (45 minutes into a trip). To simplify calculations, incidents with negative starting times are assigned a starting time of 0.00 in the incident data file and their durations are adjusted accordingly.

The severity of an incident, 'major' or 'minor', is used to determine an incident's duration and associated link speed. Major incidents are assumed to impact the network for a greater duration and cause slower speeds at the incident site. The probability of generating minor or major incidents can be set through the incident generation module.

Durations and speeds are also uniformly distributed and are calculated as random variables in the incident generation program. For major incidents, durations are assigned a minimum value of 30 minutes and a maximum value of 60 minutes; durations for minor incidents are assigned minimum and maximum values of 20 minutes and 40 minutes respectively. For generating incident speeds, major incidents are assigned minimum and maximum values of 3 miles per hour and 10 mph, respectively; minor incidents at 15 mph and 30 mph, respectively.

CASE STUDY

The objectives of the case study were three-fold: (1) to demonstrate the feasibility of using FASTCARS for data collection purposes, (2) to model the effects of familiarity and experience on real-time information acquisition and diversion, and (3) to study driver's interaction with ATIS technologies.

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 availability of 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.

Variation in travel conditions was incorporated through the simulation of incidents. Ten incident scenarios and associated HAR files were constructed for the study. The incidents files were generated from the incident probabilities assigned in the link files. At the start of each session FASTCARS was programmed to randomly select one of the ten incident scenarios.

Modeling Familiarity

It is hypothesized that drivers' familiarity with network conditions and layout are primary factors in predicting diversion and information acquisition. FASTCARS was developed to allow direct modeling of driver familiarity by incorporating hypothetical travel networks and controlling information disseminated to players. In the case study, a hypothetical network was developed and players' background levels of familiarity was controlled by varying a series of detailed maps to be assigned each player.

The case study experiment was performed with the 'Terrapin Network', a hypothetical network and city with several major freeways and arterials. The hypothetical network is depicted in Figure 5. There are six major three-lane freeways, three that run north-south, and three east-

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west. There is a major four-lane beltway that circles the city. A grid-like system of north-south and east-west arterials flow through Terrapin.

Player familiarity was controlled for by the creation of three hypothetical background experience profiles : 'low' (type 1), 'medium' (type 2), and 'high' (type 3) familiarity levels. Based on the network layout of Terrapin, 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 low familiarity players had limited information and revealed a partial set of the freeway system and distances between intersections. Medium familiarity 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 high familiarity 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. Table 1 summarizes the distribution of maps to the player categories.

This mapping of links is also used to estimate relative familiarity. The lowest familiarity level map that a link appears on is regarded as that link's expected familiarity level. Links that appear on all three sets of maps are regarded as level 1 links; they are familiar to all drivers. Links that only appear on the maps for the high familiarity players are regarded as type 3 links. Players are assumed to be familiar with their corresponding link types. For example, low familiarity players are familiar with type 1 links, medium players with type 1 and 2 links, high familiarity players with types 1,2, and 3 links. Taking the ratio of player familiarity to link types is an indicator of overall familiarity. When the ratio is greater than or equal to 1 it is assumed that players have greater experience on these links. Ratios lower than one indicate links which players have had limited experience.

Player familiarity levels were assigned after the login sequence. Before the first trial, players were randomly assigned either a low (90% probability) or medium profile (10% probability). After successfully completing three trials, players were graduated to the next level of

experience before their next trial. To model player reactions and use of ATIS, VMS, HAR, and IVNS were available to all players and message format and content did not change based on familiarity levels.

Recording Data and Scoring

To help 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.

Every FASTCARS trial produced an output event file listing each system event. 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 also included system specific data to capture the trip status at the time of the event. The record 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.

For the specific case study undertaken, a multiobjective goal set with 5 travel objectives (1) arrive at destination 20 minutes early, (2) minimize travel time, (3) minimize number of stop lights encountered, (4) minimize number of road changes, and (5) minimize trip distance was used (Adler et al., 1993).

STATISTICAL ANALYSES

Players were recruited from around the university population and included students, professors, and administrative personnel; 108 trials were collected with a maximum of 10 trials per player. During the preliminary trial, participants were introduced to FASTCARS and allowed

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to practice on a sample network. Subsequent trials were performed at the convenience of the player. Tables 2 and 3 summarize the case study.

For the data collected from the case study, a series of crosstabulations was performed to measure the strength of association between variables. Five main variables were considered for the analysis: diversion (number of diversions per trial), score (score per trial), userlevel (1=novice - low familiarity, 2=intermediate - medium familiarity, 3=expert - high familiarity), HAR (0=not used during trial, 1=used), IVNS (0=not used during trial, 1=used). A summary of the cross tabulations is presented in Table 4.

Several of the relationships show significance. There is the strength of association between userlevel and propensity to divert. During the case study, players with more experience were less likely to divert. A total of 21 of 26 expert trials had either no or a single diversion. Alternatively, among novices, almost 50 percent of the trials had at least two diversions. These results may be explained by the tendencies seen in first time players of FASTCARS. Novice players in the case study were more likely to divert at the sign of low-level congestion. As a result they often diverted several times during a trip. As players became more experienced playing FASTCARS, they gained experience that enabled them to select more efficient initial and diversion routes, thereby minimizing the need for subsequent alternations in travel.

Use of HAR and IVNS varied by user level. It was tabulated that players with higher userlevel are less likely to acquire additional information. Only 10.5 percent of all players using HAR achieved expert familiarity status and of these trials, only 4 of 26 used HAR. Similarly, only 10.5 percent of all players using IVNS were expert level players and only 2 of these 26 trials used the in-vehicle navigator. Players with high levels of familiarity generally have less need to acquire information. They are more familiar with traffic patterns and can better assess delays and congestion. In addition, their knowledge of alternate paths is also greater and thereby reduces the need to rely upon HAR and IVNS.

Player score increased as userlevel increased. Among novice players 52 percent scored over 7500 but only 10 percent scored over 9000. Among medium familiarity players 62 percent

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scored over 7500. This rose to 73 percent among expert players. On the other extreme, 33 percent of all novices scored below 5000. This fell to 15 percent among intermediate players and only one expert player failed to score at least 5000. More experienced drivers select more efficient initial travel paths and objectives that they are more likely to meet. Less experienced drivers are more likely to select inferior paths and may also specify travel objectives that are less easy to meet.

In comparing ATIS use versus player performance 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 percent (22/42) of players with scores below 5000 used HAR during the trial.

MODELING DIVERSION BEHAVIOR

It is hypothesized that driver's expectations of travel conditions and tolerance to perceived congestion varies spatially and temporally (Adler et al, 1993). Two sets of choice models, primary diversion and secondary diversion, were estimated to test this hypothesis and investigate the influence of several factors on driver behavior.

The methodology for both models involved a binary choice: At each node in the network players can decide to divert [divert = 1] or to continue on their current route [divert = 0]. Several variables were used to represent attributes of the choice situation as well as the decision maker. Attributes of the choice situation included average travel speeds, road types (freeway vs. arterial), distance from destination, presence of VMS [0 = no vms, 1-4 increased severity of travel conditions], previous diversions on this trip. Personal attributes of the players captured familiarity and experience with the current path and alternate paths available at each node. One set of variables compared the player's preassigned familiarity level to the expected familiarity level of a specific link. The ratio of familiarity levels to map-level of the link is a second indicator of network experience. Values greater than unity indicate links on which a player's experience is

greater than or equal to the lowest level of map on which the link is displayed. A second set of indicators were based on the number of previous trips during which the current route was traversed by the player. The results of the estimations are shown in Table 5; discussion of each model follows.

Primary Diversion Behavior

The primary diversion event summary file was used to develop a 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. 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 choice-based sample data set containing approximately the same number of diversions and non-diversions. The model statistics indicate a good fit with plausible coefficients.

For primary diversion six variables were found to be significant. Perceived travel speed is an important trigger to enroute behavior. Sharp decrease in travel speed increases frustration and anxiety levels in drivers and is often a precursor to enroute activity. Average link speed has a negative sign and indicates that as speeds decrease, diversion behavior is more likely.

Variable message signs are useful for forewarning drivers of downstream travel conditions. In the case study, VMS were located only on freeway links. The sign on VMS is positive indicating that messages broadcasting more severe congestion downstream triggered diversion behavior.

Along with the link specific variables of speed and VMS, the four remaining variables indicated that even under reduced speed and real-time information that tells of congestion, there are other factors that influence diversion. Experience with the current path versus possible alternate paths play a large role in the decision process. The model indicates negative sign on familiarity with the current route and positive sign on the alternate paths. As familiarity with the

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current path decreases, drivers are more likely to consider diversion. Moreover, greater familiarity with possible alternate paths positively influences diversion.

The type of road was also seen to be a significant indicator of diversion behavior. In all of the trials, players selected primary routes consisting of mainly freeway links. For the most part, primary diversion decisions were made from freeway segments to either other freeways or to surface streets. The model specifies that the sign on the road type for the alternate path is negative. This suggests that players preferred diverting to freeways and less likely to divert to surface streets.

Secondary Diversions

Expectations of travel conditions and the ability to react in real-time are integral factors in diversion behavior. A second model of diversion behavior, focusing on secondary diversions, was estimated to focus on changes that one would expect to occur once drivers have diverted away from their initial preferred route. It is hypothesized that drivers have lower levels of conflict tolerance once they enter a secondary path. As a result one would expect that drivers would exhibit a lower inertia to secondary diversion behavior.

The model of secondary behavior considered all events that took place after a player had diverted from their initial route. The variables considered for this modeling phase were identical to those used in the model of primary diversion behavior. In total there were 1000 event records of which 84 were secondary or later diversions. A choice based sample was used to form the pool of events considered for the estimation. The model statistics also indicate a relatively good fit.

Similar results to the primary diversion model were found with some notable exceptions. In this analysis three new variables (number of diversions, distance to destination, and road type of current link) entered the model and one variable was slightly changed (average link speed changed to speed ratio).

In considering secondary diversions, past diversion behavior on the trip influences behavior. The positive sign on number of diversions suggests that once players divert, they are

more likely to divert again. This may be partly explained by the route planning process. A driver may have a primary route to the destination. Once this primary route has been abandoned, drivers may not have a single secondary route to the destination but be more willing to make decisions on the go.

The distance to the destination entered the model with a positive sign. On the primary route, the distance from the destination may not be important in determining diversion. However, once away from the primary route, drivers appear to take more chances the further one is away from the destination. As one nears the destination, there is more emphasis on getting there, even a few minutes later, rather than risking worse performance by diverting.

The road type of the current path has a positive sign. This variable becomes important on secondary routes as arterial street travel becomes more likely. This variable indicates that drivers generally prefer freeway travel and even after diverting from the primary path to a surface street, drivers may weave their way through surface streets to find a new freeway to travel.

It is interesting that average link speed in not significant in this model. Rather the speed ratio, ration between perceived link speed and expected average travel speed, is significant. It is expected that drivers expectations and thresholds to perceived travel conditions vary by link and after a first diversion, drivers become less sensitive with respect to absolute speed on the path and more concerned about speed as it relates to reaching the destination.

VALUE OF USING IVNS

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 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, two comparisons were made, one assuming no costs and one assuming a 250 assessment for turning on the IVNS and a 25 per minute metered penalty. These values were compared to the actual player scores. The results are shown in Figure 6. This figure illustrates the potential improvement in score for each of the three levels of familiarity assigned to players.

It is shown that benefits of using IVNS are most realized by low familiarity players who received lower scores on average. These players generally made poorer initial route selections and used inefficient enroute diversion strategies. Conversely, it is shown that players with higher familiarity levels would experience a smaller marginal increase in score by using the IVNS.

DISCUSSION

The development of ATIS technologies requires a better understanding of the potential impacts of real-time information on driver behavior. With limited opportunity to study driver response to ATIS in the field, in-laboratory experimentation is becoming a viable alternative. Interactive simulation techniques provide the capability to model driver behavior in a controlled environment. This paper discussed the development of FASTCARS and a case study performed to model enroute diversion and real-time information acquisition behavior. FASTCARS proved to be a valuable tool for performing interactive experiments, highlighted by its ability to simulate driving decision processes, emulate ATIS, and collect data.

One of the most important findings of the case study was the identification of the importance of familiarity with network conditions and layout to enroute diversion behavior and use of ATIS. It was shown that familiarity has a significant influence on drivers' behavior and

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performance. Players with higher levels of familiarity were less likely to divert and used active ATIS systems (HAR and IVNS) less often. As player's familiarity increased they were also more likely to reach higher scores, indicative of their ability to select more efficient initial routes and improved ability to react to perceived conditions. Alternatively, players with lower levels of familiarity received lower scores and were more likely to seek real-time information. It was shown that these players could also benefit most from ATIS systems by encouraging more efficient route choice.

IMPLICATIONS FOR ATIS

The results from this initial study suggest future directions for ATIS research. The limited number of ATIS users indicates that for enroute travel, ATIS may be better suited for non-recurrent traffic conditions such as incidents and special events. Drivers with higher levels of familiarity with network conditions and layout (e.g., commuters) are better able to anticipate and react to normative congestion and may be less likely to rely on real-time route guidance information. The higher preference toward HAR over IVNS indicates that traffic condition information may be preceived as more important that route guidance. Route guidance information was found to be more significant for drivers with lower familiarity profiles.

With ATIS, and IVNS in particular, there are cost issues that may impact utilization. The tradeoffs of the information expected and the potential improvement in performance with system cost must be explored in greater detail. ATIS systems compliment but cannot substitute for personal knowledge and familiarity for mayny, if not most, drivers. Results of our study indicated that marginal return on the investment appears to decrease rapidly as drivers gain familiarity and experience.

INTEGRATION OF RESULTS

As part of the overall integration of ATIS into traffic management systems, the results from the analyses documented in this paper are being incorporated in the Advanced Traffic Management System Testbed Research Program being conducted at UC Irvine. Part of this effort is to assess the effectiveness of and traveler response to various advances traveler information systems under a broad range of implementation conditions. Figure 7 illustrates the general ATMS architecture being developed and the connections to ATIS research.

1. Dynamic Simulation: The collected data will be useful in the efforts to develop a real-time simulation capability that can operate on-line to predict dynamic response under an integrated freeway-arterial ATMS/ATIS system. DYNASMART (Mahmassani and Jayakrishnan, 1992), a dynamic network simulation program, is being used to model traffic flows under ATIS. The conflict theoretical approach and logit results described earlier are being integrated into the driver behavior routines in DYNASMART.

2. Predicting optimal or equilibrium assignment and effecting optimal real-time feedback control between freeway and arterial systems is dependent on driver behavior and response.

FUTURE APPLICATIONS OF FASTCARS

In-laboratory experimentation proves to be a valuable tool for prototyping ATIS technologies and performing preliminary investigations. There are a number of advanced application areas for which FASTCARS would be well suited:

1. Although used in this case study for special event trip making, FASTCARS can be used to model various trip types. A potential application would be to use FASTCARS to analyze commuter behavior for investigating diversion tendencies and information acquisition.

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2. FASTCARS provides a platform for conducting longitudinal studies of learning behavior. By integrating hypothetical networks, experiments could be undertaken to examine how pre-trip and enroute decisions evolve and stabilize over time.

3. Plans are underway to develop a broader pre-trip module that would enable players to receive pre-trip information for analyzing the impacts of various ATIS technologies on initial route and departure time choices.

4. Expanded emulation of ATIS technologies can be accomplished with FASTCARS. Currently in development are advanced forms of the HAR and IVNS systems used in FASTCARS. Work is continuing to make the HAR system a true real-time system without having to rely on pre-recorded messages. Enhancement to the IVHS system include a realistic graphical display of the network and the ability for two-way communications with players.

5. The concept of multiobjective travel planning is an area that deserves greater focus. Driver route preferences and how drivers form and revise objectives over time may be useful for better understanding diversion and information acquisition behavior.

ACKNOWLEDGMENTS

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Figure 1 : FASTCARS Setup

386/33 MHz Computer
Lantastic Voice Adapter
VGA Graphics

VMS · IVNS · ROAD-SIDE SIGNS · CONTROL PANEL · NETWORK VIEWER

EXTERNAL SPEAKER FOR HAR

27
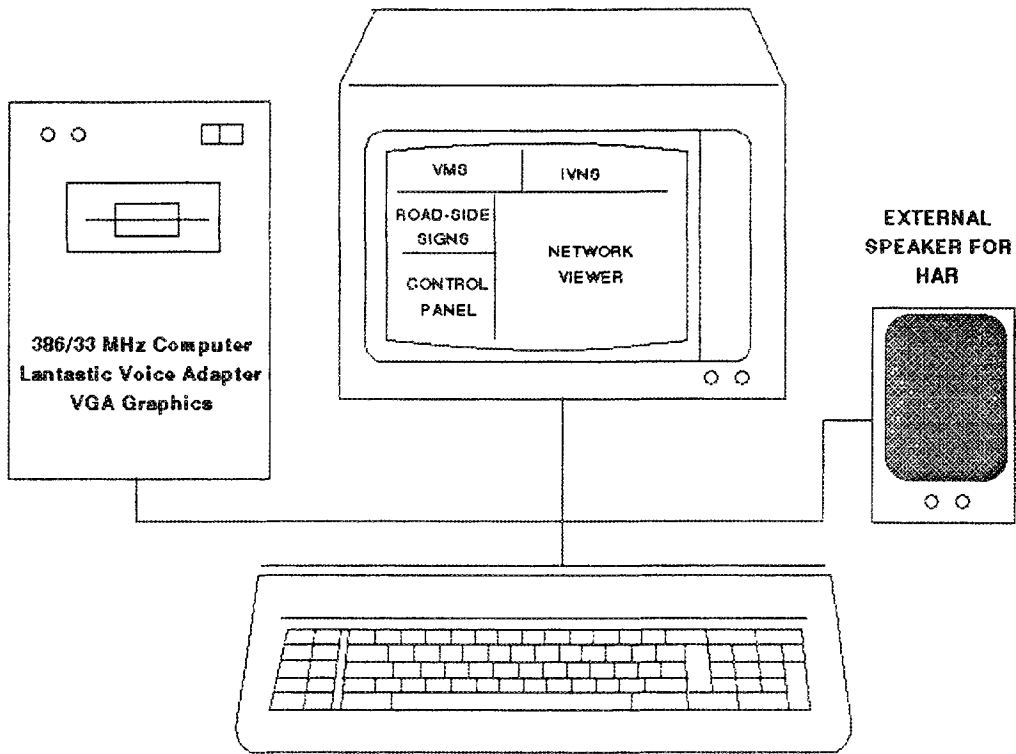
Figure 2 : Pre-Trip Planning

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┌─────────────────────────────────────────────┐
│              START PROGRAM                    │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│   LOGIN SEQUENCE : USER ID AND NAME           │
│   CHECK PAST TRIALS - UPDATE USERLVL          │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│     VIEW MAPS / SELECT INITIAL ROUTE          │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│    SPECIFY ORIGIN DESTINATION NODES           │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│    SPECIFY DEPARTURE/ARRIVAL TIMES            │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│         SPECIFY GOAL SET AND                  │
│      ASSIGN INITIAL GOAL WEIGHTS              │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│      BEGIN ENROUTE TRAVEL PROCESS             │
└─────────────────────────────────────────────┘
```

28
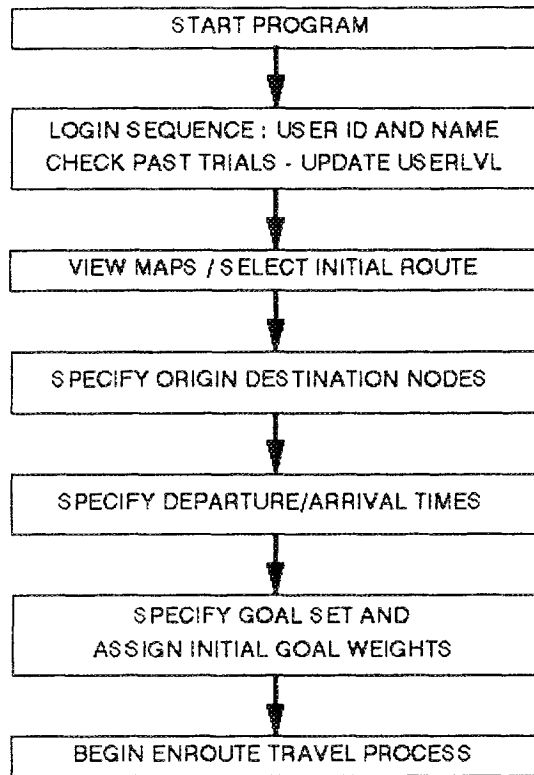
Figure 3 : Enroute Travel Process

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                    ┌─────────────────────────┐
                    │   BEGIN ENROUTE TRAVEL  │
                    └────────────┬────────────┘
                                 │
        ┌────────────────────────┼───────────────────────────┐
        │                        ▼            YES             ▼
        │         ┌──────────────────────────┐      ┌──────────────────┐
        │         │  REACHED DESTINATION ??   │─────▶│    POST-TRIP     │
        │         └──────────────────────────┘      │   EVALUATION     │
        │                        │                   └──────────────────┘
        │                    NO  ▼
        │  ┌──────────────────────────────────────────────────────────┐
        │  │                ENROUTE ASSESSMENT                         │
        │  │  ┌──────────────┐ ┌──────────────────┐ ┌──────────────┐  │
        │  │  │ PERCEPTION OF │ │ PASSIVE INFORMATION│ │  VIEW MAPS  │  │
        │  │  │TRAVEL CONDITIONS│ │   ACQUISITION    │ │             │  │
        │  │  └──────────────┘ └──────────────────┘ └──────────────┘  │
        │  └──────────────────────────────────────────────────────────┘
        │                        │
        │                        ▼
        │  ┌──────────────────────────────────────────────────────────┐
        │  │           ENROUTE BEHAVIORAL ADJUSTMENT                   │
        │  │  ┌─────────────┐ ┌─────────────┐ ┌─────────────┐         │
        │  │  │ CHANGE LANE │ │ CHANGE ROAD │ │ DO NOTHING  │         │
        │  │  └─────────────┘ └─────────────┘ └─────────────┘         │
        │  │  ┌──────────────────┐     ┌──────────────────┐           │
        │  │  │ ACTIVE INFORMATION│    │  REVISE TRAVEL   │           │
        │  │  │   ACQUISITION    │     │   OBJECTIVES     │           │
        │  │  └──────────────────┘     └──────────────────┘           │
        │  └──────────────────────────────────────────────────────────┘
        │                        │
        └────────────────────────┘
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Figure 4 User Interface

VMS - NEXT EXIT INFORMATION SIGNS	CONTINUE AHEAD 2.8 MILES TURN LEFT AT TERRAPIN BELTWAY Minimum Travel Time : 34:11 minutes Remaining Distance : 25.6 miles

ROAD SIDE
INFORMATION SIGNS

CLOCK	6:30:17
CAR SPEED	39.00
60 Time to Event	59:42
20 Min Trip Time	0:17
10 Min Stop Light	0.0
5 Road Changes	0.0
5 Trip Distance	0.2
PENALTIES	176.0

JFK AVENUE EASTBOUND

30
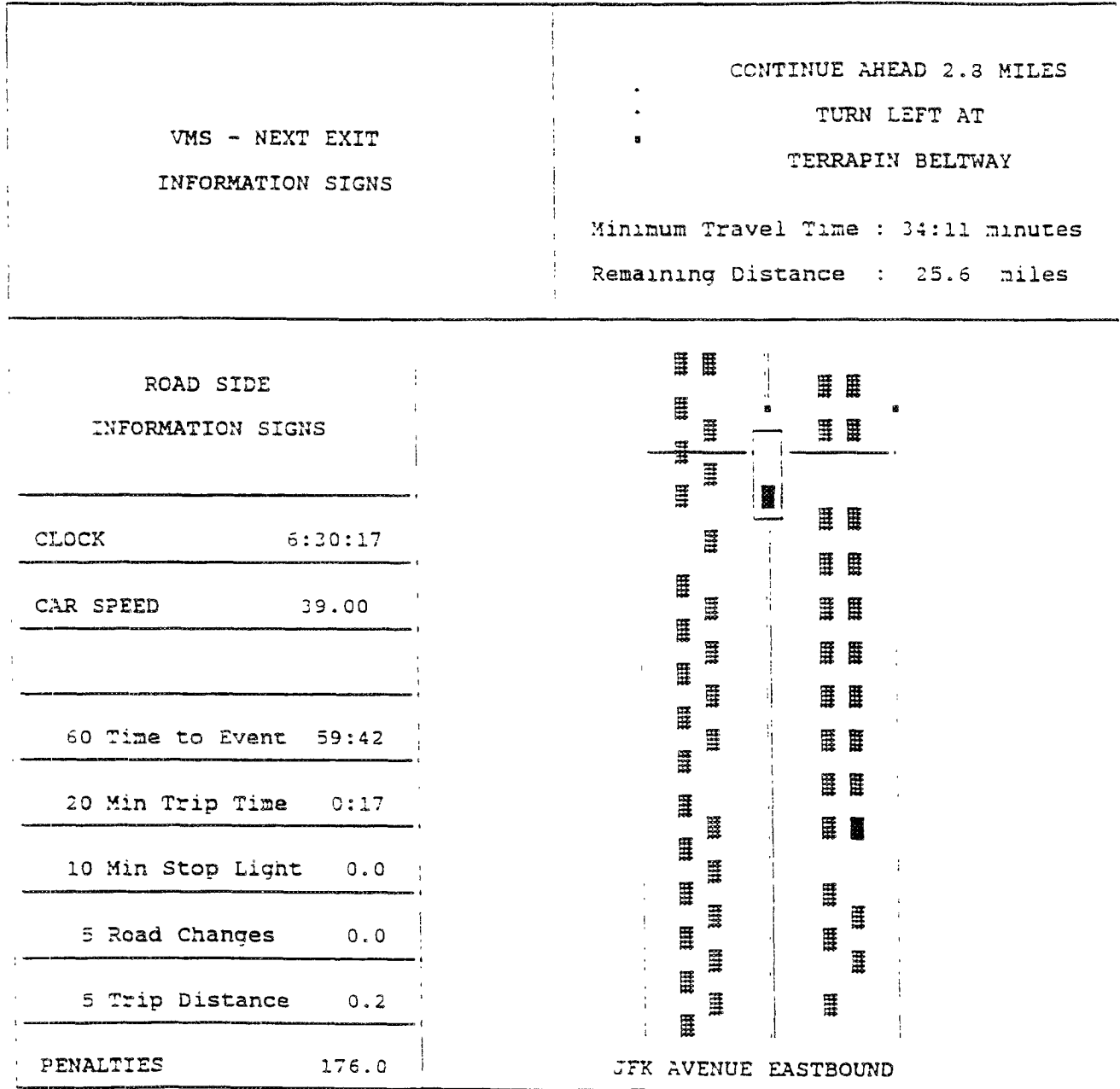
Figure 5 : Fastcars Data Flow

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┌─────────────┐   ┌─────────────┐   ┌─────────────────┐   ┌─────────────┐
│  PLAYERS    │   │NETWORK INFO │   │TRAVEL OBJECTIVES│   │  ROADSIDE   │
│  DATA FILE  │   │ STREET DATA │   │      DATA       │   │   SIGNS     │
│             │   │  LINK DATA  │   │                 │   │             │
└─────────────┘   └─────────────┘   └─────────────────┘   └─────────────┘
                           │
┌─────────────┐      ┌──────────────┐              ┌─────────────┐
│ ARR/DEP TIMES│ ──▶ │   FASTCARS   │              │  HAR FILES  │
│  O-D NODES   │     │ INPUT DATA   │              │             │
└─────────────┘      │    FILE      │              └─────────────┘
                     └──────────────┘                     │
                            │                             │
                            ▼                             ▼
                  ┌────────────────────┐         ┌──────────────┐
                  │                    │         │INCIDENT FILES│
                  │  FASTCARS PROGRAM  │ ◀─────── └──────────────┘
                  │                    │
                  └────────────────────┘
                            │
          ┌─────────────┬───┴───┬─────────────┐
          ▼             ▼       ▼             
  ┌─────────────┐ ┌─────────────┐ ┌─────────────┐
  │   UPDATED   │ │ SIMULATION  │ │  KEYBOARD   │
  │   PLAYERS   │ │   EVENT     │ │  COMMAND    │
  │  DATA FILE  │ │  DATA FILE  │ │  DATA FILE  │
  └─────────────┘ └─────────────┘ └─────────────┘
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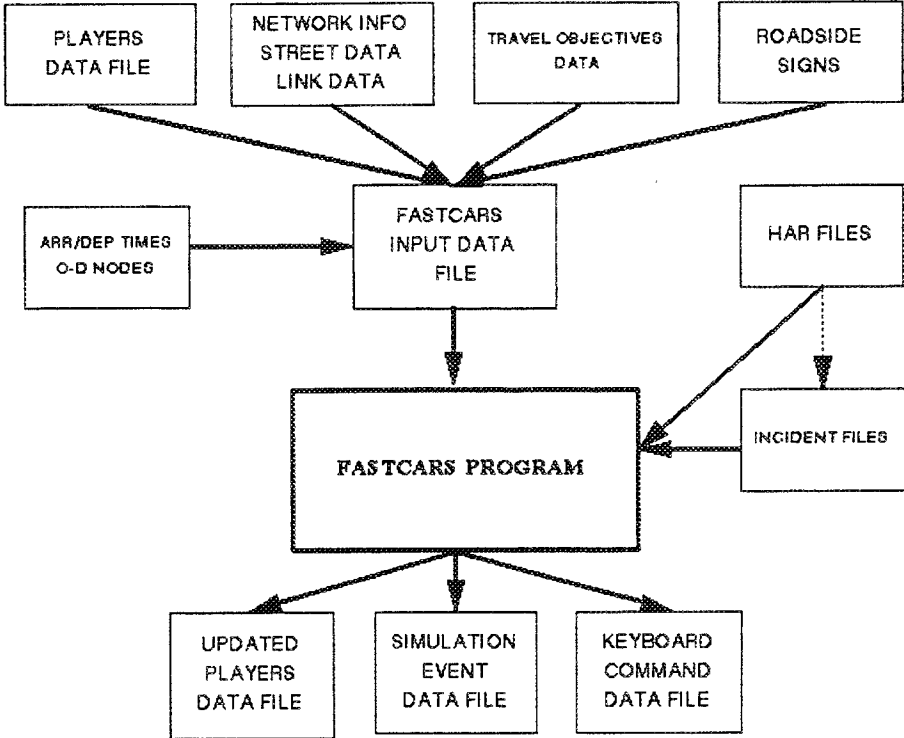
31

Figure 6 Hypothetical Network
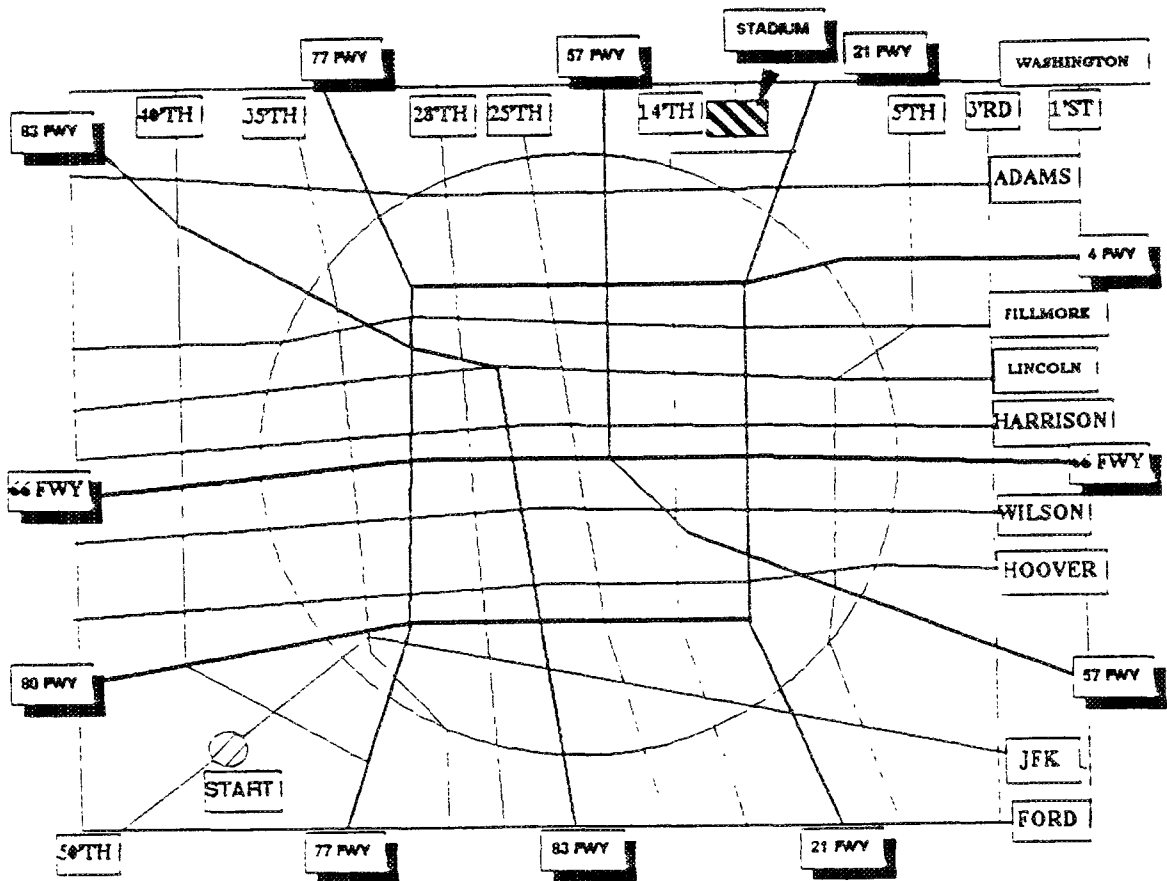

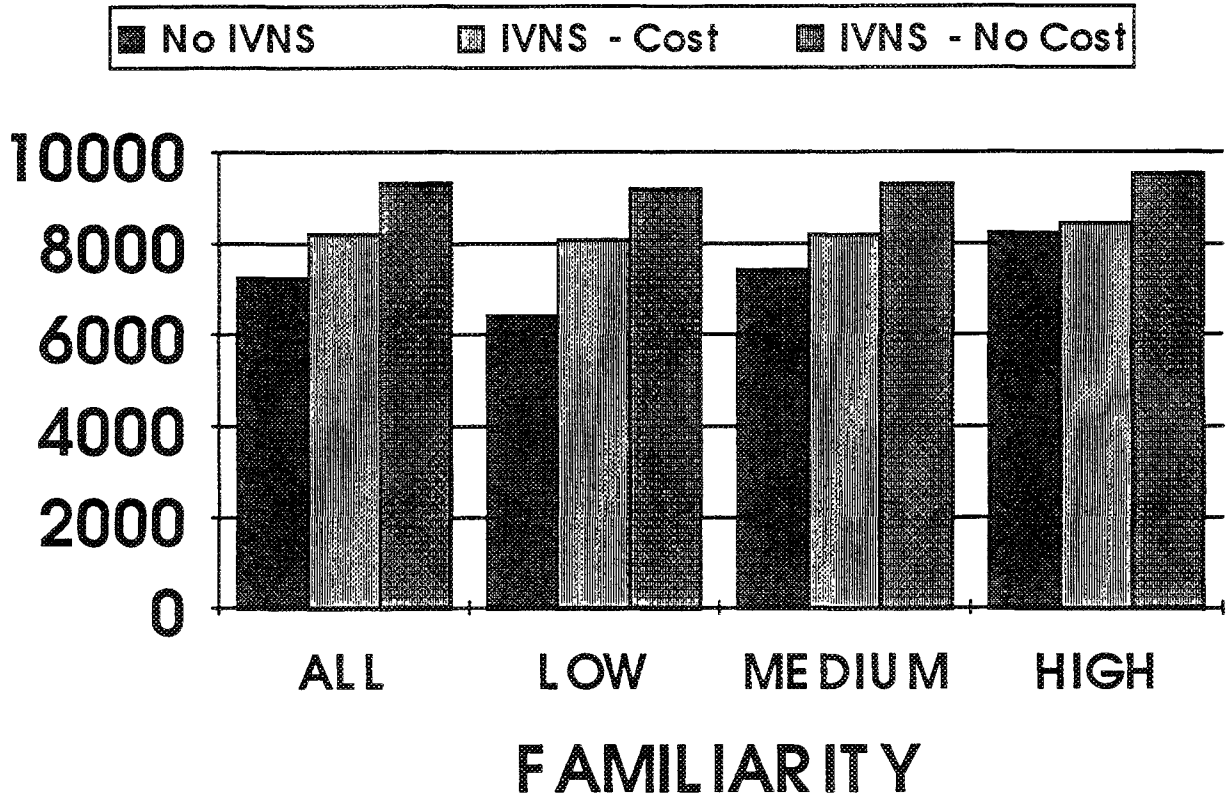Figure 6 Hypothetical Network

Figure 7 IVNS Usage

Table 1 Distribution of Familiarity Maps

Low Familiarity - 2 Maps Subset of Freeway System, No Arterials	(1) General Network Layout (2) Freeway Distances
Medium Familiarity - 3 Maps Entire Freeway System, Partial Arterial	(1) General Network Layout (2) Freeway Distances (3) Freeway Speed Profile
High Familiarity - 5 Maps Entire Freeway and Arterial Systems	(1) General Network Layout (2) Freeway Distances (3) Freeway Speed Profile (4) Arterial Speed Profile (5) Freeway Incident Probability

Table 2 Summary Statistics

VARIABLE	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Score	7242.45	2633.97	-638.45	9860.76
Userlevel	1.87	0.77	1.0	3.0
Diversions	1.35	1.71	0.00	8.00
Trip Time (secs)	2833.09	658.12	1884.20	4815.90
Ave Speed (mph)	37.96	5.17	23.30	50.10
Road Changes	6.41	2.37	2.00	17.00
Trip Distance	29.16	4.19	23.00	44.30

Table 3 Frequency of ATIS Usage

	Did not use	Used during trial
HAR	70	38
IVNS	89	19

Table 4 Crosstabulations

VAR 1	VAR2	DF	X^2
Diversion	Familiarity	6	7.03
Score	Familiarity	8	23.35
Diversion	Score	12	55.43
Use HAR	Familiarity	2	5.96
Use IVNS	Familiarity	2	2.48
Use HAR	Diversion	3	8.40
Use IVNS	Diversion	3	8.51
Use HAR	Score	4	18.81
Use IVNS	Score	4	7.23

Table 5 Models of Diversion Behavior

INDEPENDENT VARIABLE	Primary Diversion Coefficient (t-statistic)	Secondary Diversion Coefficient (t-statistic)
Model constant	5.45 (3.76)	-1.41 (-1.00)
Average link speed	-0.0088 (-3.71)	
Ratio of perceived to expected link speed		-2.30 (-2.28)
Previous trips on current link	-1.55 (-3.19)	
Familiarity with current path	-3.86 (-3.70)	-2.30 (-2.85)
Familiarity with alternate path	3.49 (3.50)	1.80 (2.26)
Road type of current path [0=freeway, 1 = arterial]		-3.44 (-3.46)
Road type of alternate path [0=freeway, 1 = arterial]	-1.57 (-2.23)	4.34 (4.25)
VMS	0.50 (1.81)	
Number of previous diversions		1.12 (4.58)
Distance to destination		0.16 (3.37)

MODEL STATISTICS

Initial Log Likelihood	-89.42	-111.59
Log likelihood at convergence	-33.83	-54.96
Likelihood Ratio Test	110.82	113.26
Number of observations	129	161
Percent correctly predicted	88.372	85.71
Rho-Squared	0.6217	0.5057