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Working Paper
UCTC No. 127

**The University of California
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**A Conflict Model and Interactive Simulator (FASTCARS) for Predicting
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ABSTRACT

This paper proposes a theoretical methodology and practical data collection approach for modeling enroute driver behavioral choice under Advanced Traveler Information Systems (ATIS). The theoretical framework is based on conflict assessment and resolution theories popularized in psychology and applied to models of individual consumer behavior. It is posed that enroute assessment and adjustment is a reactionary process influenced by increased conflict arousal and motivation to change. When conflict rises to a level at which conflict exceeds a personal threshold of tolerance, drivers are likely to alter enroute behavior to alleviate conflict through either route diversion or goal revision. Assessment and response to conflict arousal directly relate to the driver's abilities to perceive and predict network conditions in conjunction with familiarity of network configurations and accessible alternate routes.

Data collection is accomplished through FASTCARS (Freeway and Arterial Street Traffic Conflict Arousal and Resolution Simulator), an interactive microcomputer-based driving simulator. Limited real-world implementation of ATIS has made it difficult to study or predict individual driver reaction to these technologies. It is contended here that in-laboratory experimentation with interactive route choice simulators can substitute for the lack of real-world applications and provide an alternate approach to data collection and driver behavior analysis. This paper will explain how FASTCARS is useful for collecting data and testing theories of driver behavior.

INTRODUCTION

Enroute driver decision making is a complex process. Limited understanding of drivers' behavioral differences and cognitive processing abilities make it difficult to estimate enroute behavior. Several key factors are known to influence enroute choice including, but not limited to, perception and knowledge of current path conditions (delay, expected travel time, congestion level), knowledge (or perception) of the existence of alternate routes and travel conditions on these routes, affinity toward taking risks, thresholds of tolerance to traffic conditions, and certainty of meeting travel goals or expectations. In addition to these variations within a population, driving behavior also varies for individuals based on trip characteristics such as trip type, time of day, and other considerations.

This paper presents a methodology, based on conflict arousal and motivation, to aid the understanding of enroute driver behavior and provides a direction for exploring the impact of real-time traffic condition information on behavioral choice. It is argued that a conflict model, combined with an overall goal-oriented approach to travel behavior, can provide the basis for modeling enroute behavioral choice and may be extended to estimate a general model for both static and dynamic driver behavioral choice. Central to the formulation are two basic suppositions: (1) a driver's actions are directed toward meeting a set of travel goals, and (2) changes in behavior occur only as a direct result of the driver's perception that these travel goals will

not be achieved. Decisions to divert or otherwise change from original travel plans occur when a threshold of tolerable conflict is exceeded, and the driver perceives an alternate course of action that would reduce the perceived level of conflict below that threshold. To test the approach, an interactive computer-based driving simulation, FASTCARS (Freeway and Arterial Street Traffic Conflict Arousal and Response Simulator), was developed. FASTCARS integrates a driver simulation program with the conflict model approach to create a data collection tool for analyzing enroute driver behavior.

MODELING ENROUTE BEHAVIOR WITH CONFLICT THEORY

Conflict theory, formally rooted in psychology and applied to areas of human behavioral choice such as consumer behavior, provides a basis for describing this enroute assessment and adjustment behavioral process. Conflict theory is based on the idea that humans act either to address internal needs or in reaction to external forces. The basic theory states that behavioral response is predicated by stages of conflict arousal and motivation. Arousal is the stimulation that evokes reaction; motivation is the behavior that effects reaction. Arousal and motivation stem from an internal need to fulfill goals and the resultant activities are a function of all variables that arouse and direct behavior (Madsen, 1964).

Conflict arousal results from unexpected changes in the environment that conflict with a person's prior experiences and expectations. Cofer and Appley (1964) suggest that conflict is a special case of frustration and anxiety brought on under conditions when a "motivated organism is thwarted from reaching its goal behavior". Conflict arousal causes a tension that motivates response and action through periods of frustration and dissatisfaction with the current state based on perceived impediment of desired goal attainment (Markin, 1974; Goicoechea et al., 1982).

Response to conflict situations can be predicted by certain cognitive elements that will become salient during response. The response will be influenced by (1) the amount of arousal, (2) the motivation of decision maker during choice, (3) factors of the problem domain, and (4) associations among cognitive elements. A primary factor in predicting an individual's response to conflict arousal is a function of personal thresholds to tolerable conflict, the degree of conflict severity above which people attempt to respond to the situation (Hebb, 1972; Schroder et al., 1966).

Individual behavioral 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, situational factors impact threshold levels of each decision-maker on a trial-by-trial basis.

The process of conflict reaction and response covers the time interval from when conflict is first experienced until the time after which the choice process ends, by either eliminating or circumventing the perceived conflict (Hansen, 1972). Monarchi (1972) states that conflict can be resolved in two ways: innovation and adaptation. Innovation alludes to the search for new directions and altering one's actions or behavior in response to conflict. Adaptation denotes a restructuring of objectives and expectations so that decision makers increase threshold tolerance and become more content with the current state.

The methodology for modeling enroute behavior is based on these concepts of conflict arousal, motivation, and response. It is assumed that travel behavior that deviates from the initially intended pattern must result from increased conflict arousal and motivation. Under ideal travel conditions it would be unlikely that drivers would attempt to alter their travel path. But, as perceived travel conditions worsen on the initial route, the likelihood of failing to meet the desired travel goals increases. Moreover, this sense of impending failure often causes a corresponding increase in frustration, tension, or anxiety that induces behavioral change.

PROPOSED MODELING FRAMEWORK

The proposed framework for modeling enroute driver behavioral choice is based on conflict theory and is constructed through the relationships between driver behavior, cognitive processing abilities, and components of the decision making process shown as 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.

Figure 1 : General Schema for Driver Behavior Model

Although the focus of this research is on enroute behavior, to enable a complete modeling approach it is important to not overlook the importance 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. 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.

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.

Figure 2 : Enroute Travel Process

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 the value of trip-making. All decisions reflect the goal set and the importance of attaining the specified objectives.

Conflict Arousal and Motivation: After the goal set has been established, it is assumed that drivers select an initial route and departure time to best satisfy the objective and goal specification scheme. Once the trip has begun, as long as this initial route choice remains optimal it is presumed that the driver will not change travel plans. If traffic conditions deteriorate and conflict arousal increases drivers may gradually or eventually consider adapting the trip pattern. The degree of motivation and the level and severity of conflict together determine if drivers adapt travel patterns and what the response will be.

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. Under what conditions do

drivers seek information and how this information is then used for decision making are useful for better understanding enroute driver behavior.

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. Factors that influence response are discussed later in this paper.

PRE-TRIP PLANNING

Antonisse et al. (1989) suggest that route choice behavior involves a two-stage process of identifying a set of alternatives and evaluating this choice set based on driver and trip conditions as well as route attributes. 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 a given trip can be developed from driver characteristics and perceived route utilities. A driver's behavioral characteristics lead to a set of travel goals; perceived travel utilities express the attractiveness of a particular route to this driver. 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 satisfied choice for the driver for this single trip. Likewise, it must be assumed that drivers attempt to select an initial route choice strategy that will lead to the highest probability of meeting the travel goals.

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, $G_d^{it}(X)$, for driver d can be given as :

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

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 henceforth, the superscripts i & t will be assumed)

Although drivers approach route choice differently, the decision process may be modeled by standard modeling methods. For this analysis, a *Weighted Objective Decision Method* was assumed. In this 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 the goal attainment level multiplied by the relative weight. The selected alternative is the one that maximizes the expected utility,

$$\hat{U}^r = \sum_{g=1}^G W_g \hat{V}_g^r \quad (2)$$

where:

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

Perceived Expected 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. For any trip at a given time there is an actual value of utility V for a route, however, this value of utility is unknown to the driver. Instead, each driver bases his decisions on some perceived level of utility. This perceived utility may be stated as the actual utility biased by personal behavior (e.g., risk) and an uncertainty factor ρ such that:

$$\hat{V}_g^r = \rho_g^r V_g^r \quad (3)$$

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 $\rho = \rho + \Delta\rho$.

ENROUTE ASSESSMENT AND ADJUSTMENT BEHAVIOR

Enroute, 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.

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.

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, or:

$$\hat{U}^r < \bar{U}^r \quad (4)$$

where:

$$\begin{aligned} \bar{U}^r &= \text{Threshold utility level for route } r. \\ \hat{U}^r &= \text{Perceived utility on route } r \end{aligned}$$

$$= \sum_{s=1}^G w_s \hat{V}_s^r = \sum_{s=1}^G \rho_s^r w_s V_s^r$$

Motivation and Response to Conflict

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 ' i ' is greater than the utility projected for the current path ' c ' by some improvement threshold η :

$$\hat{U}^c + \eta < \hat{U}^i \quad (5)$$

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

$$\sum_{g=1}^G \rho_g^c W_g V_g^c + \eta \leq \sum_{g=1}^G \rho_g^i W_g V_g^i \quad (6)$$

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:

$$U'^c = \sum_{g=1}^G \rho_g^c W'_g V_g^c \quad (7)$$

and the route switching rule is now based on:

$$\text{Max} (U'^c + \eta, U''^i) \quad (8)$$

These weights may change in response to conflict several times during the course of a trip. 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.

Treating Uncertainty

The partwise components (V) of the utility function are dependent on a drivers 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 at the current location or on the current route) 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.

REAL-TIME INFORMATION ACQUISITION AND PROCESSING

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 the case of imminent congestion. Limited knowledge also impacts evaluation and any subsequent choice of alternate travel strategies. Uncertainty or ignorance of the availability and performance of alternate routes reduces the likelihood of diversion. In many cases, real-time information, in the form of either 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 increased 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.

SIMULATION APPROACH TO MODELING INDIVIDUAL DRIVER BEHAVIOR

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 and, (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" (Bovy and Stern, 1990).

Interactive computer-based simulation is growing in popularity among transportation researchers. Programs have been developed to analyze individual choice as well as system performance impacts. Examples include the Urban Driving Simulator (UDS) (Leiser and Stern, 1988) that was developed to study subjective time and speed estimations, and IGOR (Interactive Guidance On Routes) (Bonsall and Parry, 1991) that was implemented to study drivers' compliance with route guidance advice.

Other forms of simulation have also been used in transportation. Allen et al. (1991) describe in-laboratory research on a driving simulator that combines microcomputer processing with video imaging to simulate the driving process. Ayland and Bright (1991) discuss a gaming simulation tool, programmed around a commercially available computer game, to study the impacts of in-vehicle driver information. Mahmassani and Herman (1988) and Mahmassani and Jayakrishnan (1991) 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. More advanced approaches, such as endoscopes and fixed-based vehicle simulators, have also been developed to study various aspects of driving. While these latter approaches are more realistic and better for analyzing ergonomic factors of driving, they are very costly to develop and have not yet been used extensively (Bovy and Stern, 1990).

FASTCARS DRIVING SIMULATOR

FASTCARS, in conjunction with the modeling framework proposed, 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 hypothetical traffic network, simulated real-time information technologies, and interactive driver travel choices. FASTCARS is designed to model enroute travel decision making. FASTCARS provides an artificial environment that replicates spatial and temporal situations that arouse conflict and motivation during travel. The combination 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. Its 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.

Although FASTCARS was specifically created to study the theoretical framework and hypotheses presented in this paper, the program may be used to test a variety of theories and hypotheses. FASTCARS may be used to study how behavior varies with respect to trip type. The program may be used to model commuting, special event, or leisure trips. Similarly, the availability of ATIS and network conditions may be controlled. Using the goal weight functions, FASTCARS may be used to analyze how drivers adapt their behavior as the objectives change. There are many other studies that could be performed with FASTCARS.

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.

The program was initially designed and implemented to model the conflict theories posited above. FASTCARS is useful for designing experiments to analyze enroute driver behavior in response to conflict arousal, motivation, and information acquisition. In the simulation, conflict may be initiated in two forms: through a driver's direct perception of worsening travel conditions or by acquiring real-time information stating such network conditions. In either case, the simulator may be used to induce varied levels of conflict on players. Decisions made during the game, such as setting goal weights, diverting, and acquiring information, are influenced by players' characteristics and experience playing the game. By establishing patterns between behavioral tendencies and action it is possible to formulate theories and hypotheses that may be tested with the aid of FASTCARS.

User Scoring and Evaluation

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 logistic scoring functions are , one for each goal, normalize the value of goal attainment 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 1.

Table 1 Example Goal Set

		Ideal	Normalized	Threshold	Normalized
1.	Minimize schedule delay (minutes)	-15.0	0.90	0.0	0.30
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

Goal Set and Preference Weights:

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 minimize total travel time. 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 that 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, fewer slowdowns, and no stops at red lights.

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 6). At any stage of the game, the value of attaining each goal, V_i , 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.

Emulating ATIS

FASTCARS presents drivers with two types of information, basic road signs and advanced traveler information systems. Basic road-side 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. Two types of road signs are periodically displayed to the user. The first road sign is a "next exit" sign that is displayed to users while traversing freeway links. These signs, similar to those typically seen on highways, displays a list of the upcoming exits and their distances in miles. The second road side information sign, available on both freeway or surface links, is used to provide either general directional information or to point out upcoming major junctions. Examples include, "Stadium Next Right", "Freeway Junction Ahead", or "Tune to Highway Advisory Radio".

The objective of FASTCARS is to study the impact of perfect information availability on driver behavior. Since the program uses static traffic data prepared in the link file, the simulated information technologies are able to provide users with perfect information of network performance during the playing of the game. Issues of imperfect information are not considered here. 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.

Variable message signs are "passive" information sources that provide drivers with a series of short messages usually directed to traffic conditions and navigation guidance within a limited radius of the sign. VMS are passive because they appear to the driver without any active attempt to search and acquire.

Highway advisory radio is an "active" information source providing drivers with a larger scope of network conditions. Generally, HAR provides a broader range of information that often includes not only current traffic information but other data such as lane closing and maintenance work in the near future. It is limited in that drivers must pay special attention to the radio to accurately hear and acquire the desired information. Also the lack of visual contact places greater emphasis on cognitive mapping and processing.

In-vehicle guidance offers drivers a direct source for finding the shortest path to their destination. Through a computerized system, IVNS typically gathers real-time information and specifies to 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.

Variable message signs, displayed at certain freeway locations as determined in the link file, 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 five miles ahead on the current freeway to gather data on the traffic conditions that are scheduled to be encountered. The message sign is posted for a period of one and two minutes depending on the speed of the driver. Multiple messages that need to be displayed are rotated on a twenty second cycle. Several variations of messages are available depending on the severity of traffic conditions.

Highway Advisory Radio is the second information technology simulated by FASTCARS. With the addition of a Lantastic Voice Adapter, players can 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 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.

The final real-time information technology emulated in FASTCARS is a prototype shortest-time in-vehicle navigator. 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 ("up" to continue straight ahead, "right" to turn right, and "left" to turn left) in which the driver should turn at the next intersection or freeway exit to follow the shortest time path. The same information is presented in sentence form. Like VMS and HAR, IVNS provides players with perfect information based on the game administrators design of the network.. Players who follow the advice of the navigation system will reach the destination in the shortest time from the current location.

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.

Data Flow

FASTCARS provides significant flexibility for changing network configuration and system parameters. Network files may be interchanged together with variations in origin and destination nodes and departure times to alter the game playing environment. All of these variables are input to the simulation at its inception.

The basic network configuration is a collection of nodes and links. Nodes are identified as intersections or crossings of two roadways. Links are defined as connections between an **output arc** of one node to an **input arc** of a different node. Data profiles for the nodes and links are stored in separate external data files which must be specified at the start of a session.

FASTCARS records two output files from interactive player session. The first file records a list of keystrokes and clock times for each action. This file may be replayed with FASTCARS in "Playback" mode to review any data collection session. The second file saved is an event data file. This file records a list of important events that took place during the game session. Player actions such as road and lane changes, activating the various information systems, and revising goals are recorded as well as system events such as display of road side signs and road advancement. Together 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 comprehensive account of what was taking place in the simulation at the time of a player decision.

USING FASTCARS TO STUDY BEHAVIOR

Figure 3 depicts a sample network on which a driver is following the 77 Freeway toward the destination. As the driver approaches the 66 Freeway Interchange, there is a VMS indicating congestion ahead. The 'X' marks a potential diversion alternative.

Figure 3 : Example Travel Network

For this scenario, it is possible to graph 'Perceived Conflict' versus 'Time' for the driver on the 77 freeway. Initially, the driver does not perceive any congestion and as a result, there is a low level of perceived conflict. The information acquired via the VMS causes the driver's conflict level to rise above the threshold. This is depicted in Figure 4. The arrows on the graph indicate potential diversion points. The bottom of the graph indicates speed reduction and the site of the incident.

Figure 4 Graphing Perceived Conflict versus Time

It is possible that for some drivers on the freeway, the VMS arouses conflict but not to a level that exceeds the threshold. Some drivers may decide to turn on HAR to acquire further real-time information or advice. This is depicted in Figure 5.

Figure 5 Graphing the Combined Impact of VMS and HAR

Should the perceived conflict be very severe and the 66 Freeway deemed a viable diversion route, some drivers may choose to divert. Figure 6 depicts the changes in perceived conflict and threshold levels between routes. It is possible that threshold levels are route dependent and perceived levels of conflict on primary versus diversion routes influence driver behavior differently. This figure suggests that a given driver may have a higher level of tolerance to conflict on a diversion route. Therefore, should a driver experience similar levels of conflict on the diversion path, the behavioral response may not be similar.

Figure 6 Changes in Conflict Arousal During Diversion

Using FASTCARS it is possible to simulate the decision processes used by the driver to divert and acquire real-time information. Knowing the distance from the destination, the state of the system, the information

presented, the goal set and weights, and the behavioral characteristics of the drivers being sampled, it is possible to model this diversion behavior.

CONCLUSIONS

The framework discussed in this paper proposes a new direction for analyzing enroute driver behavior and the impacts of real-time information on the decision making process. The construction suggests that there are general relationships for explaining enroute driver behavioral choice. Three primary factors: (threshold of conflict tolerance, motivation improvement index, and value of information) directly influence diversion behavior and real-time information search and acquisition. 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 exceeding 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.

Based on this framework, this paper has described the development of FASTCARS, a simulator designed for collecting driver behavioral choice data. FASTCARS is designed to capture goal-directed driver behavior under conditions of real-time traffic information availability. 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.

For evaluating the impacts of real-time information technologies on driving, FASTCARS has been equipped to emulate three types of advanced traveler information systems: Variable Message Signs, Highway Advisory Radio, and In-Vehicle Navigation Systems. These systems provide driver with real-time information in different formats and contents.

In addition, the simulation is designed to be flexible and easily adaptable 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.

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