Dynamic Interactive Simulator for Studying Commuter Behavior Under Real-Time Traffic Information Supply Strategies

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A new simulator for laboratory studies of the dynamics of commuter behavior under real-time traffic information (advanced traveler information systems) strategies is described, and a set of laboratory experiments that used this simulator is discussed. The purpose of the experiments was to examine the behavioral processes underlying commuter decisions on route diversions en route and day-to-day departure time and route choices as influenced by the provision of real-time traffic information. Both the real-time and day-to-day dynamic properties of traffic networks under alternative information strategies—particularly issues of convergence to an equilibrium, stability, and benefits following shifts in commuter trip timing decisions—will also be investigated in the experiments.

Various efforts have been initiated worldwide to develop intelligent vehicle highway systems (IVHSs). Major demonstration projects and research programs can be found in the United States, Europe, and Japan (*1–4*). There are three general clusters of IVHS technologies with application to commuter mobility: advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), and advanced vehicle control systems (AVCS) (*5*). Essentially, IVHS uses advanced information processing and communications technologies to manage traffic, advise drivers, and, eventually, control the flow of vehicles to improve efficiency and safety.

ATIS is especially targeted to assist drivers in trip planning and decision making on destination selection, departure time and route choices, congestion avoidance, and navigation to improve the convenience and efficiency of travel (*6,7*). Various ATIS classes have been defined from Class 0 static, open-loop systems, to Class 4 dynamic, closed-loop systems, enabling two-way communication between the vehicle and the traffic control center (*8*). Because of limited real-world implementation of ATIS technologies, it has been impractical for researchers to evaluate how real-time information availability influences driver behavior. The purpose of this paper is to introduce a dynamic multi-driver interactive simulator as a tool to assess travel behavior in response to ATIS information supply features. Special attention is given to the spatial/temporal context of the potential responses.

Several methodological approaches have been proposed to assess the effectiveness of various possible forms of ATIS to reduce recurrent and nonrecurrent traffic congestion and examine the interactions among key parameters, such as nature and amount of information displayed, market penetration, and congestion severity (*9–13*). Furthermore, various human factors studies have been conducted concerning the attentional demand requirements of in-vehicle navigation devices and their effects on the safety of driver performance, using either a driving simulator or specially adapted vehicles in real urban environments (*14–16*). Mail-back surveys and telephone interviews on drivers' willingness to divert en route in response to real-time traffic information and their preferences toward the different features of these systems have also been conducted (*17–20*).

Three computer-based interactive simulators have been developed to study commuter behavior through laboratory experiments as an alternative and precursor to real-world applications. Interactive Guidance on Routes (IGOR) was developed by Bonsall and Parry for investigating factors affecting drivers' compliance with route guidance advice, such as quality of advice and familiarity with the network (*21*). Allen et al. used an interactive simulator to study the impacts of different information systems on drivers' route diversion and alternative route selection (*22*). Freeway and Arterial Street Traffic Conflict Arousal and Resolution Simulator (FASTCARS), developed by Adler et al., was used to predict en route driver behavior in response to real-time traffic condition information based on conflict assessment and resolution theories (*23*). All these simulators are deterministic, with all traffic conditions and consequences of driver actions predetermined, and no consideration of network-wide traffic characteristics. These simulators can interact with only one subject at any given time, ignoring interactions among drivers in the same traffic system. Bonsall and Parry's simulator provides different preset levels of information quality to the experimental subject in a preset sequence. In addition, the effect of the drivers' responses to the information on the traffic system is not considered. The simulators of both Allen et al. and Adler et al. assume the information supplied to be correct and static, which does not represent actual real-time ATIS environments.

Driver behavior and responses to real-time traffic information systems are the result of a complex process involving human judgment, learning, and decision making in a dynamic environment. Uncertainty in this dynamic environment originates from the fact that (a) the consequences of an individual

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driver's decision depends on the decisions of other drivers in the network and (b) the interactions that determine these outcomes take place in the traffic system and are highly nonlinear. In particular, a "recommended" path predicated on current link trip times may be less than optimal as congestion in the system evolves. Hence, the accuracy of the information provided to participating drivers and the resulting reliability of this information as a basis for route choice decisions are governed by the dynamic nature of the driver-decision environment and the presence of collective effects in the network as a result of the interactions of a large number of individual decisions (*24,25*). Consequently, driver decisions on the acquisition of the information system and compliance with its instructions are influenced by the users' perceptions of the reliability and usefulness of the system. These perceptions are formed mostly by learning through one's own experience with the system, as well as reports by friends, colleagues, and popular media. This is a long-term process that depends on the type and nature of the information provided, in addition to the individual characteristics and preferences of the driver.

The ideal way to study this long-term process is by observing actual driver decisions in real-world systems. However, as noted earlier, in the absence of sufficient deployment of the technologies of interest, it is practically difficult to obtain real-world data on the actual behavior of drivers under different real-time information strategies, on a daily basis, together with the various performance measures affecting these responses. A set of controlled "laboratory-like" interactive experiments involving real commuters in a simulated traffic system is proposed in this paper, following Mahmassani and Herman's work on interactive experiments for the study of tripmaker behavior dynamics (*26*). Such experiments could play an important transitional role in gaining fundamental insights into behavioral phenomena that will play a key role in determining the effectiveness of ATIS and ATMS strategies.

This paper describes a new simulator, developed at the University of Texas at Austin, that offers the capability for real-time interaction with and among multiple driver participants in a traffic network under ATIS strategies. The simulator allows several tripmakers to "drive" through the network, interacting with other drivers and contributing to system evolution. It considers both system performance as influenced by driver response to real-time traffic information and driver behavior as influenced by real-time traffic information based on system performance. The simulators reviewed earlier are primarily computer-based devices that display predetermined stimuli and elicit and collect the participants' responses. The simulator described here actually simulates traffic. Its "engine" is a traffic flow simulator and ATIS information generator that displays information consistent with the processes actually taking place in the (simulated) traffic system under the particular information supply strategy of interest. The decisions made by the driver participants are fed directly to the simulator and as such influence the traffic system itself and the subsequent stream of information stimuli provided to the participants.

In addition to studying users' responses to ATIS information for a particular commute on a given day, the simulator allows the researcher to investigate the day-to-day evolution of individual decisions under such information strategies. This longer-term dimension is missing from most available studies of the effectiveness of real-time information systems. Our experiments consider system evolution and possible equilibration by including the participants and the performance simulator in a loop whereby tripmakers may revise their decisions from one iteration day to the next. These experiments are intended to investigate both the real-time and day-to-day dynamic properties of traffic networks under alternative information strategies, particularly issues of convergence to an equilibrium, stability, and benefits following shifts in user trip timing decisions.

The context for this paper is that of morning peak-period commuters in congested traffic corridors. The intended interactive experiments can be divided into three categories: (a) pre-trip and en route path selection only, (b) pre-trip departure time and path choice and en route path selection, and (c) pre-trip departure time and path choice, real-time departure time adjustments and en route path selection. In each category, each subject is asked to "drive" a vehicle to the central business district (CBD) through a corridor network. Each subject (or user) is provided with real-time traffic information before each trip. On the basis of this information, the user independently supplies his or her departure time and path decisions. These decisions are in turn fed into a traffic simulation and path assignment model (*11,12*). Each subject's vehicle is then moved along the selected path according to the prevailing traffic condition on the link that the vehicle is on. At each junction where the user has the opportunity to switch to an alternative route, he or she is again provided with real-time traffic information and asked to decide whether to stay on the current path or switch to an alternative route. Feedback is supplied to the subject at the end of the trip on the consequences of his or her decisions and new decisions are sought accordingly for the next day's trip. This process is repeated until system convergence is achieved or a predetermined number of iterations is exceeded.

SIMULATOR DESCRIPTION

System Architecture

The simulator developed to perform the interactive experiments is an application of the client/server modeling concept used extensively in X Window System applications (*27*) (see Figure 1). The simulation-assignment model (as an X client) used is an extension of the corridor model developed by Mahmassani and Jayakrishnan (*9*) and modified by Mahmassani and Chen (*10*) to include pre-trip path selection in addition to en route switching decisions. The code for this model was written in FORTRAN and is run on an IBM RISC System/6000 (as a host computer). An additional program (as another X client) was written using X library functions (X Window System, version 11, release 3) to control the layout of windows displayed on the screens of a set of Macintosh and Intergraph computers (used by subjects, one computer per subject) on which either MacX 1.1 (for Macintoshes) or X11 R4 (for Intergraphs) is being run. Written in C, this program is linked to the simulation-assignment model using a number of C library interface routines available under IBM AIX, version 3.2, an implementation of the AT&T System V–based version of the UNIX operating system. X Window System protocol

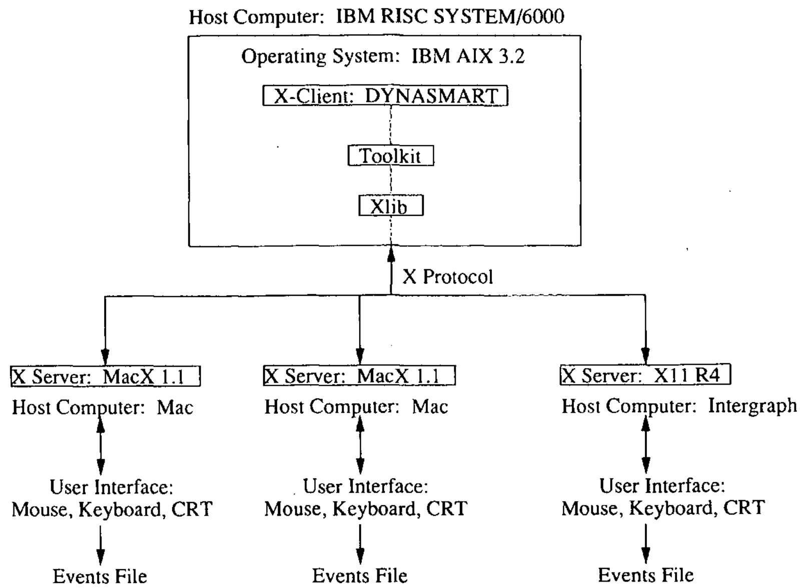

FIGURE 1 Client/server model.

is a low-level graphics description language used by the X clients and servers to exchange information.

The Macintosh computers (Quadra 700s, IIs, and Pluses) and Intergraph InterPro 2020 workstations, used as front-end host computers, are connected in the LocalTalk local network in the Civil Engineering Micro Laboratory at the University of Texas at Austin. An AppleTalk protocol is used to allow these computers to communicate with each other and a Kinetics Fast Path is used to bridge the local network to the IBM RISC System/6000 at the Center for High Performance Computing at the University of Texas at Austin.

Unique Features

This interactive simulator possesses several unique features for the study of user behavior under ATIS. First, this simulator has multi-user capabilities. It is programmed to accommodate a number of users simultaneously. Practically, this number is limited by the capacities of the communications hardware and software (AppleTalk and Kinetics Fast Path) and the host computer running the simulation-assignment model. Our experiments are designed to have an upper limit of about 100 participants in a given session. Different market penetration rates (of on-board equipment) can be considered by simulating the decisions of each participant as those of an analyst-specified number of vehicles in the system.

Second, this simulator is dynamic. All user responses are fed into the simulation-assignment model and thus directly influence prevailing traffic conditions. There are no predetermined consequences for the subjects' responses, other than those that result from the nonlinear interactions taking place in the traffic system.

Third, this simulator can be run in real time. It is now calibrated in such a way that every simulation time step conforms to the speed of the host computer's clock. Naturally, other desired simulation speeds can also be achieved.

Fourth, the experiments using the simulator are intended to be collective but not collaborative in design. Information supplied to each subject is tailored to reveal network traffic conditions that pertain to the subject himself or herself only. The subject cannot obtain direct information on other subjects in the system through the simulator, although talking among participants, such as comparing commuting experiences, is not prohibited.

In summary, this interactive simulator provides participating commuters a dynamic commuting environment in which they can interact with one another and with the simulated system in a real-time setting.

Driver-Machine Interface

All the human-machine interface with a given participant takes place via the computer (in this case, Macintosh or Intergraph) assigned to him or her. Information to participants is shown on the monitor screen and each participant either uses the mouse to move the cursor to the space provided on the screen or uses the keyboard to click or type in his or her response. The layout of the information displayed on the monitor screen is shown in Figure 2. Each participant is provided with a view of the basic network configuration and his or her relative vehicle position in the network at all times. The only exception is during post-trip evaluation, when he or she might examine the trip history. Each participant's vehicle is moved according to real-time decisions. Different situational messages are displayed to respondents in the space provided on the screen as per the occurrence of each situation following system evolution. Participants will be alerted by a "beep," produced by the built-in audio device in Macintosh or Intergraph computers, every time a message is displayed. Because the simulator uses the X window system, it is easy to add or delete messages (information) when needed. Human factors engineering was considered in the development process to follow principles of

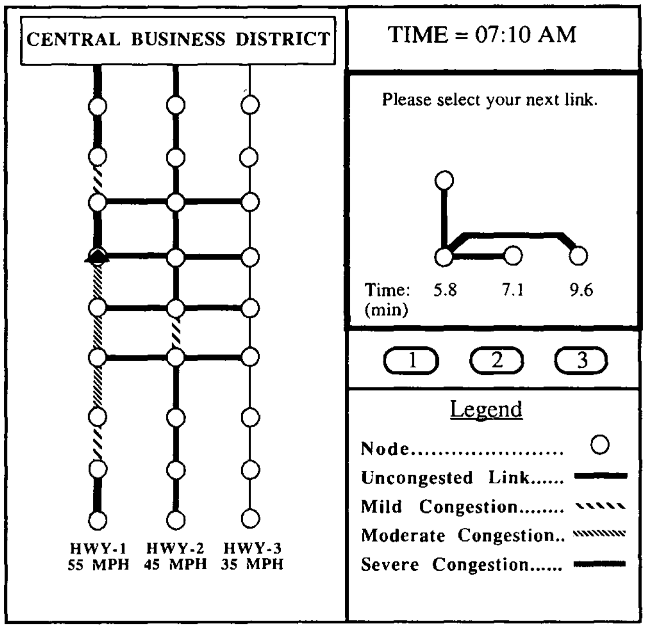

FIGURE 2 Layout of information display.

design, such as good visibility, natural mapping, and good feedback (*28,29*). Moreover, the amount of information displayed to subjects at any given time has been limited to prevent overloading subjects' short-term memories (*30*).

Simulation-Assignment Model

The simulation-assignment model is based on the corridor network version of the DYNASMART model developed at the University of Texas at Austin (*31,32*), which was previously used in the experiments of Mahmassani and Chen (*10,25*). The model is composed of three main components: the traffic performance simulator, the network path processing component, and the user decision-making component (see Figure 3). The first component is a fixed time-step macroparticle traffic simulator. Vehicles on a link are moved individually at prevailing local speeds consistent with macroscopic speed-density relations (modified Greenshield's model). Inter-link transfers are subject to capacity constraints. For the given network representation and link characteristics, the simulator uses a time-dependent input function to determine the associated vehicular movements, thereby yielding the resulting link trip times, including estimated delays associated with queueing at nodes. These form the input to the path processing component, which calculates the pertinent path trip times, which are in turn supplied to the participating commuters and the user decisions component. The latter is intended to predict the responses of the simulated commuters in the system to the available information according to a set of behavior rules described in the next section. The simulator can consider a variety of information strategies. The primary strategy used to date has been of the so-called TRAVTEK variety: prevailing trip times on the network links with no attempt by some central controller or coordinating entity to predict future travel times. Another function of the second component is to translate the user path selection and switching decisions into time-varying link flow patterns on the network's links. Further detail on the simulation-assignment methodology can be found in the paper by Mahmassani and Jayakrishnan (*9*).

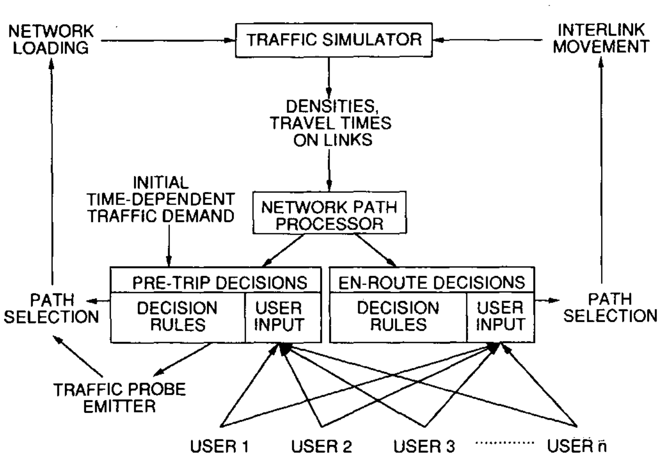

FIGURE 3 Simulation-assignment model.

Path Selection and Switching Rules

During our experiments, commuter decisions may be made by actual participants, as well as by simulated tripmakers, reflecting the desired fraction of equipped users in the simulated system. Two alternative rules may be used in the user decision component for both en route path switching and initial route selection: (a) a "myopic" deterministic choice rule and (b) a boundedly rational rule. An important concept in both rules is the notion of a current path, whereby the commuter is assumed to have an evoked current path to which he or she might exhibit some degree of commitment. In a freeway corridor context, such an evoked path might be strongly associated with the freeway itself or with a major alternative parallel arterial. Under the myopic rule (Rule R.1), the simulated commuter will always select the best path (in terms of least cost or least travel time) from the current node n to the destination, that is

$$\delta_i(n) = \begin{cases} 1 & \text{if } TTC_i(n) > TTB_i(n) \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where

$\delta_i(n)$ = a binary indicator equal to 1 if user i switches from the "current" path to the "best" path between node n and the destination; otherwise it is equal to 0;

$TCC_i(n)$ = trip time on "current" path from node n to destination of user i, and

$TTB_i(n)$ = trip time on "best" path from node n to destination of user i.

Under the myopic rule, the commuter will switch paths in pursuit of any gain, no matter how insignificant. A more reasonable assumption is that driver switching behavior exhibits a boundedly rational character anchored in one's current path. This assumption was operationalized by Mahmassani and Jayakrishnan (9) in the following boundedly rational switching rule (Rule R.2). It states that a driver will switch from his or her current path to the current "best" alternative only if the improvement in the remaining trip time exceeds some threshold, which may be expressed either in absolute terms or relative to the remaining trip time. In this work, we follow Mahmassani and Jayakrishnan's original version of this rule, with a relative indifference band subject to a minimum (absolute) trip time saving, namely:

$$\delta_i(n) = \begin{cases} 1 & \text{if } TTC_i(n) - TTB_i(n) > \max[\eta_i(n)TTC_i(n), \tau_i(n)] \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where

$\eta_i(n)$ = relative indifference band for user i, as a fraction of remaining trip time on current path from node n to destination (i.e., $TTC_i(n)$, with $\eta_i(n) \geq 0, \forall i,n$); and

$\tau_i(n)$ = minimum improvement in remaining trip time, from node n to destination, necessary for user i to switch from his or her current path, with $\tau_i(n) > 0, \forall i,n$.

Of course, Rule R.1 is a special case of Rule R.2, with $\eta_i(n) = 0$ and $\tau_i(n) = 0, \forall i,n$. In this model, $\eta_i(n)$ is expressed in relative terms. It can be thought of as the percentage of improvement in the remaining trip time vis a vis the current path. Moreover, to preserve a meaningful threshold effect and to preclude unintended switches when $TTC_i(n)$ becomes very small as the driver approaches his or her destination, the absolute band $\tau_i(n)$ is introduced to provide a lower bound. Both $\eta_i(n)$ and $\tau_i(n)$ could either be fixed constants or vary from node to node and possibly over time. Furthermore, they could be related systematically to the sociodemographic attributes of the commuter population. (The simulation results presented in this paper assume fixed values for these bands for a given simulated commuter over the duration of his or her commutes.) In addition, while $\eta_i(n)$ is allowed to vary across simulated commuters, $\tau_i(n)$ is taken as a constant τ for all simulated drivers.

It is the desire to obtain an observational basis for the calibration of these indifference bands or generation of alternative behavioral constructs that motivates the experimental approach described in this paper. It is important to note that in the experiments described in this paper, there are two sources of tripmaker decisions in the system. First, the actual participants themselves provide decisions that are directly incorporated in the simulation, immediately affecting the paths of the corresponding simulated vehicles. The second source of decisions is the behavioral rules in the user decisions component. These apply only to vehicles in the system that do not correspond to actual participants in the experiments. The relative numbers of vehicles moving according to each source depends on the particular experimental scenario under consideration.

As noted earlier, the above rules could be applied en route as well as at the trip origin, primarily in connection with descriptive real-time information with self-optimization capability, which could provide estimates of the remaining trip time on the simulated commuter's current path as well as identify the "best" path.

Commuting Context

The participating commuters are placed in a simulated commuting corridor with three major parallel facilities, such as freeways or major arterials, for the morning work commute. For convenience and with no loss of generality, all three facilities are 9 mi long, and each is discretized into nine 1-mi segments, with crossover links at the end of the third, fourth, fifth, and sixth miles to allow switching from any facility to any of the other two (see Figure 4). Of the three major facilities, hereafter referred to as Highways 1, 2, and 3, Highway 1 has the highest free mean speed of 89 km/hr (55 mph), followed by Highway 2 (72 km/hr or 45 mph) and Highway 3 (56 km/hr or 35 mph). All the crossover links have a free mean speed of 72 km/hr (45 mph). Simulated commuters enter the corridor through ramps feeding into each of the first six 1-mi segments on each facility and commute to a single common destination downstream (such as the central business district or a major industrial park).

In the experiments conducted to date and used in prototype development, 1,800 commuters depart from each of the first

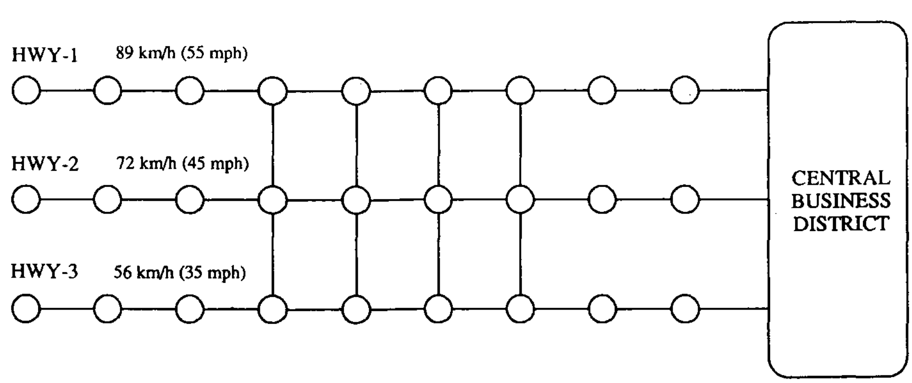

FIGURE 4 Commuting corridor with three parallel facilities.

six (residential) sectors toward the destination. The departures are spread uniformly over a 20-min period, with the loading periods for each sector staggered with a time lag of 5 min between adjacent sectors, with sector 1 starting first. Departing rates are 60 vehicles per minute for Highway 1, 20 vehicles per minute for Highway 2, and 10 vehicles per minute for Highway 3 for each sector. Note that this assignment constitutes intended paths for the commuters.

The simulator can also accept different network configurations and loading patterns. Such information could be developed for a real network with which the participants might have firsthand familiarity.

Data Collection

Before participation in an experiment, each subject is assigned an identification number, and a corresponding record file is created. At the beginning of each simulation run, the subjects are asked to provide their respective numbers so that the simulator can recognize each subject and store their responses during the simulation in their respective record files. All records are event-based and are written in a format ready for analysis.

METHODOLOGY

In a given experiment, a fraction (possibly equal to one) of the commuters are assumed to have access to real-time traffic information, from both an on-board and a home-based traffic advisory unit. The equipped commuter receives information on the prevailing trip times on all the links of the network. These form the basis for computing the trip times from the user's present location (either at the origin or en route) to his or her destination along alternative paths. A behavioral assumption is made in the definition of available paths in a corridor network of the type considered here, namely that users perceive and identify a path in terms of its major highway facility, reflecting a hierarchy in the manner in which users perceive a particular network. Thus a path for the purpose of this analysis consists of a single major facility (to the destination) along with its connecting link. Consequently, at any given node (including the origin), the user effectively considers only three paths, one for each facility.

Experimental Design

A commuter faces three principal decision situations when supplied with real-time traffic information: (a) pre-trip planning and adjustment, (b) en route assessment and diversion, and (c) post-trip evaluation (see Figure 5). At the post-trip evaluation stage, a commuter examines the trip he or she has just completed against the actual post-trip data for that day and decides his or her intended departure time and route for the next day's commuting trip. When he or she "gets up in the morning," he or she can consult the pre-trip information update supplied and determine accordingly if any departure time adjustment or route change, or both, is desirable. Once the commuter begins the trip, he or she can switch routes

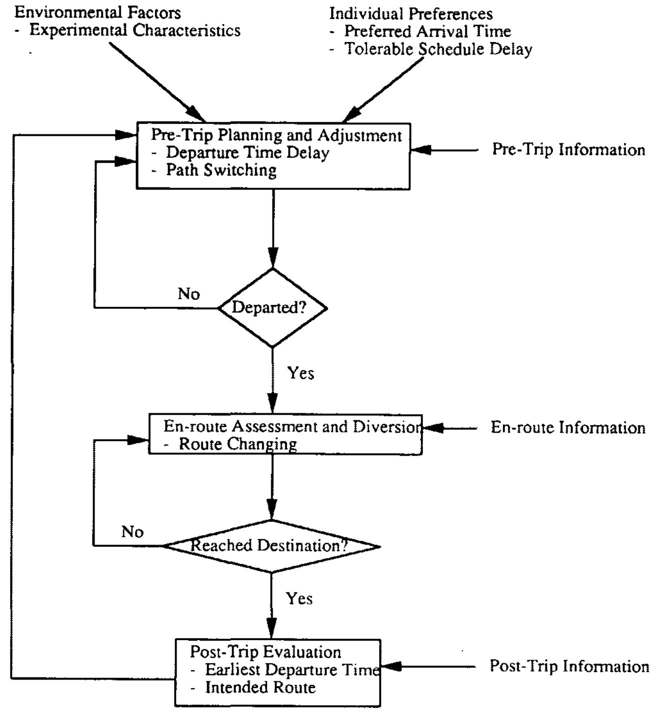

FIGURE 5 Conceptual framework for commuting decision process with real-time traffic information.

only in response to the congestion reported by en route information systems.

Three types of experiments were performed to study the mechanisms underlying the real-time, day-to-day dynamics of individual decisions under real-time traffic information strategies in the context of the overall system's evolution (including issues of convergence and stability):

- En route assessment and diversion only;
- En route assessment and diversion plus post-trip evaluation; and
- En route assessment and diversion, post-trip evaluation, and pre-trip planning and adjustment.

Descriptions of these experiments follow.

Experimental Procedures

Because the third type of experiment encompasses the first two, it is described in detail. In this type of experiment, en route assessment and diversion, post-trip evaluation, and pre-trip planning and adjustment are all available to the participant. Each subject is first asked, before engaging in any interactive experiments, to provide responses to a set of attitudinal questions. This precommuting survey is administered through computer interaction, with the participants prompted by and responding directly on the monitor screen of the computer assigned to him or her. Among other attitudinal questions, each subject is prompted to supply his or her preferred arrival time (given work start time) as well as lateness allowed at work. Once specified, these two quantities will remain fixed for the subject throughout the experiments.

All participants are required to complete a number of trips to the CBD through the corridor network, corresponding to a series of day-to-day morning commutes. Initially (day 0), each participant is supplied with a plot of the average trip time by time of departure over the whole departure period from his or her origin on all three paths to the destination. These trip times are obtained from a simulation run with all 10,800 simulated vehicles without actual participants. Each participant is asked to select a target earliest departure time (the earliest time that he or she would start a commuting trip regardless of what the traffic condition would be like at that time) and a target path. This is intended to capture pre-trip planning decisions taken "the night before." The chosen target earliest departure time and path determine the stimulus displayed to the participant on the next day, that is, on day 1.

When the simulation of the peak period starts, each subject is provided with a continuous display of the commuting corridor with the level of congestion on every link in the network updated in real time and a clock displaying the current (simulated) time on the screen. Once a participant's target earliest departure time is reached, the screen will display a blow-up of all possible paths for him or her to take, together with the expected trip time on each path. The participant has to decide whether to depart now or to delay departure until a later time. If the participant chooses to leave now, he or she will so indicate this choice by selecting a path (which may or may not be the target path). Otherwise, the participant will be provided with the same blow-up of possible paths on the screen at the next simulation update with the expected path trip times at that time. The participant then will decide again if he or she wants to depart at that time or later.

Once the participant enters the network, he or she will receive real-time updates of his or her vehicle's position in the corridor display. It is as if the participant is driving the little car in the display through the corridor on the screen. When the vehicle arrives to a node where route switching is possible, i.e., crossover links are available, the participant's screen will display a blow-up of all available paths and the expected trip time of each path. At the same time, all the links emanating from the current node are highlighted on the corridor display. The subject then decides whether to stay on the current route or switch to an alternative route. Furthermore, if the vehicle gets stuck in the link-end queue, a warning will be displayed in the situational message box to alert the driver.

When the participant reaches the destination (the CBD), the path taken for the trip will be highlighted on the commuting corridor displayed. He or she will then be supplied with a feedback table providing summary statistics on the decisions made during the trip, the information supplied, and the consequences of the decisions. For instance, the table contains the departure time and path, route switches en route, arrival time, and total trip time. A summary of the principal types of information displays is provided below:

- Continuous background
  - Layout of commuting corridor,
  - Current time display box,
  - Trip information display box, and
  - Interaction box.
- Dynamic information: pre-trip planning
  - On corridor layout, link condition, color coded and commuter origin, highlighted;
  - In information display box, updated plots of average trip time (Type 3 only), blow-up of available links/paths, and current trip time on each path;
  - In interaction box, prompt for departure (Type 3 only), select departure or delay, click box (Type 3 only), prompt for path at origin, select path, click box.
- Dynamic information: en route
  - On corridor layout, link condition, color coded and vehicle position;
  - In information display box, blow-up of available links/paths at node, current trip time on each path to destination, and situational text messages, e.g., queue status;
  - In interaction box, prompt for path at node and select path, click box.
- Post trip evaluation information
  - On corridor layout, path taken, highlighted;
  - In information display box, table of trip summary statistics and plots of average trip time by time of departure for current iteration (Types 2 and 3 only);
  - In interaction box, prompt for departure time and path for the next iteration (Types 2 and 3 only) and type in departure time and path (Types 2 and 3 only).

At the end of the simulation, the subject will again be provided with a plot of the average trip time by time of departure, over the departure period from his or her origin on all three paths, obtained from this simulation run (Day 1). Each participant is again asked to select a target earliest departure time (as previously defined) and a target path for Day 2. This process continues until the nth simulation run, by which time either the traffic system has reached convergence or a preset number of iterations has been exceeded. The procedure for this type of experiment can be presented in algorithmic form as follows:

- Step 0: Initialization
  a. Perform simulation run with no participant input;
  b. Generate trip time versus departure time plots, by path, for each origin, for $j = 0$; and
  c. Set $j = 1$.
- Step 1: Previous day's information
  a. Display trip time versus departure time, by path, for Day $(j - 1)$;
  b. For each participant i, obtain
  - $TEDT_i(j)$ = target earliest departure time, for Day j, and
  - $TP_i(j)$ = target path, for Day j.
- Step 2: Pre-trip decisions
  a. $t = 0$, initiate SIMULATION;
  b. If $t \geq TEDT_i(j)$, display updated trip time versus departure time, by path, for Day j, and prompt participant i for departure status and path;
  c. If response for prompt positive, $ADT_i(j) = t$ and go to Sept 3— otherwise, set $t = t + \Delta t$, call SIMULATION and return to Step 2b.
- Step 3: En route decisions
  a. Run SIMULATION; increment $t = t + \Delta t$, move vehicles;

b. For each participant with ADT_i $(j) \leq t$,
   i. Check if at destination: if yes, go to Step 3c: otherwise continue.
   ii. Check if at decision node: if yes, display trip time (by path), prompt route choice, read user selection and/or apply default route; otherwise, continue.
   iii. Return to Step 3a
c. Check if $t \geq T$: if yes, continue; otherwise, go to Step 3a.

- Step 4: Post-trip Evaluation
  a. Highlight path taken on corridor layout,
  b. Display table of trip summary statistics.
- Step 5: Convergence Check

If convergence reached, or $j > N$, STOP; Otherwise, set $j = j + 1$, go to Step 1.

The procedures for the other two types of experiments are similar. In Type 2 experiments, the subject's vehicle is loaded into the network at his or her specified departure time because the option to adjust the departure time in real time is unavailable. In Type 1 experiments, the subject's vehicle is loaded into the network at a preassigned departure time, which may not be changed by the participant.

Experimental Factors

The interactive experiments are intended to investigate the effect of six principal factors: departure origin, background traffic, decision time constraint, rate of information update, simulation time frame, and information display strategies.

Departure Origin

Depending on his or her origin, the driver may have four, three, two, or only one opportunity for en route switching. This may affect his or her propensity to switch. Different departure origins are assigned at random to the participating subjects. Once assigned, each participant's origin remains unchanged throughout all experiments.

Background Traffic

Background traffic is the simulated traffic that interacts with the participants' vehicles in the same corridor network. There are 10,800 simulated vehicles, some of which do not switch routes because they are not equipped with traffic advisory units or their drivers do not rely on real-time information. The equipped vehicles (reflecting the particular market penetration scenario of interest) switch routes according to the behavioral rules described in "Path Selection and Switching Rules." The relative proportions of the two types of vehicles and the behavioral rules are under the analyst's control.

Decision Time Constraint

This is the time constraint imposed on real-time decisions. At the origin, the participant has a limited amount of time to decide if he or she will depart and on what path. If the time runs out before a response has been supplied by the participant, he or she does not leave. During the trip, if the participant is faced with a route-switching decision and does not respond within the time limit, he or she will continue on the current route (default option). This time constraint can be adjusted to simulate real-life driving time constraints under various traffic conditions.

Rate of Information Update

The time between each real-time information update will be varied to observe effects on the participants' decisions as well as overall system performance. This should yield insights into what an optimal update rate might be.

Simulation Time Frame

Two versions of the interactive experiments have been developed. One version performs the simulation and user interaction at a rate that is synchronous with real time. The other version performs the simulation and user interaction at a faster pace than real time.

Information Display Strategies

Three different display strategies are considered here. The first strategy is to supply route-based trip time information only when the subject's vehicle reaches a decision node, that is, one where there are opportunities for path switching. The second strategy is to display route-based trip time information at all points along the trip to the destination and update this information at the rate of information update as another controlled factor, as mentioned previously. The third strategy is to provide route-based trip time information only when requested by the participant, in this case by using the mouse to move the cursor to the space provided on the screen.

CONCLUDING COMMENTS

One of the principal determinants of the effectiveness of real-time traffic information systems is the user's response to this information, both in real time and over the long run. The available body of knowledge in this area is very limited and will remain rather speculative until a meaningful observational basis has been developed. Laboratory-like experiments of the type described in this paper can provide a low-cost alternative for a much needed start on acquiring observations of actual tripmakers. Three unique features of the experimental apparatus and procedures described in this paper should be stressed: (a) the stimuli provided to the participants are generated by a traffic simulation model and are therefore both internally and externally consistent with real-world traffic conditions, (b) the interactive multiuser capability introduces greater realism, especially at higher market penetration levels, and (c) the day-to-day aspect of the experiments addresses an essential question that has often been ignored in discussions of ATIS effectiveness.

The kind of data that can be obtained from such controlled conditions provides a basis for the development of user-response models that may be used in simulation-assignment tools to evaluate network performance under real-time information. The richness of these data and the dynamic interactive nature of their sources raise challenging methodological questions in terms of analysis, particularly model specification and parameter estimation. It is therefore necessary to advance the state-of-the-art methodologically to take advantage of such data and properly address the behavioral questions of interest. Naturally, simulators and laboratory-like experiments of the type described in this paper are not intended to totally replace actual field demonstrations and tests. Their role is to provide a relatively low cost and rapid test bed to address key fundamental issues that are critical to further develop and deploy IVHS technologies. Insights gained from such experiments can then guide the cost-effective development of full-scale field tests. Further discussion of the role of laboratory-like experiments in the hierarchy of approaches for the study of complex large-scale systems is given by Mahmassani and Herman (*26*).

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