

An Interactive Tool for Collecting Traveler Behavior Information

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ABSTRACT

Understanding driver behavior and response to traffic information is necessary in order to achieve the maximum benefit from Advanced Traveler Information Systems (ATIS). This paper describes the development of a travel simulator to collect information on driver route choice in response to traffic information. A main feature of the simulator is the realistic representation of multiple traffic information sources (currently VMS and radio messages). Furthermore, the simulator is one of the first Internet-based travel simulators, and the only one that accurately simulated the driving task. The simulator consists of collection of pre-trip information and default route information followed by multiple simulated trips with varying incidents and traffic information. The simulator is evaluated and measures well against established guidelines for travel simulator development. Results will be discussed in future papers as data collection using the simulator is ongoing as of August 2007.

Keywords: travel simulation, route choice, driver behavior, ATIS, interactive web survey

INTRODUCTION

Advanced Traveler Information Systems (ATIS) are playing an ever increasing role in managing the congestion on roadway networks. It is evident that government and transportation authorities have recognized this fact given the increased spending on ATIS systems. However, these efforts only achieve maximum effectiveness when it is understood if and how users will respond to the information provided. Studies on traveler behavior and response to traffic information are often difficult due to the high costs associated with revealed preference studies which examine actual driver behavior.

Alternatively, travel simulators enable observation of driver behavior in controlled laboratory setting. In a travel simulator, a user 'drives' from an origin to a destination while receiving indications of trip progress and various forms of information regarding the network state. Bringing participants in for interview and supervision while completing a survey is expensive and time-consuming. With the advent of the Internet, however, it has been possible to perform such surveys on-line for several years. Unfortunately, it appears few have yet taken advantage of this new technology. The survey tool developed in this project takes advantage of newer technologies to perform such investigations at both a reduced cost and to reach a broader audience.

This paper describes the development of a new travel simulator developed to collect traveler route choice behavior in response to traffic information. An examination of previous work in travel simulator development follows, after which the experimental design of the simulator is discussed. The simulator is then evaluated in a discussion strengths and weaknesses. Finally, this paper offers conclusions and perspectives on future work.

PREVIOUS WORK

A number of traffic simulators have been developed for research use. However, in keeping with the distinctions made by Koutsopoulos et al. (1) and Polak and Axhausen (2), this paper only focuses on simulators that have been developed to collect route choice behavior with respect to Advanced Traveler Information Systems (ATIS), and not those that are developed for other ATIS purposes or to simulate the driving task as closely as possible.

Spurred by the advanced of personal computing, initial interest in developing interactive route choice simulators began in the early 1990's. One of the earliest works in building a travel simulator to collect route choice behavior was IGOR (Interactive Guidance On Routes), developed by Bonsall and Parry (3,4). IGOR implemented a small-town network with random variability in traffic conditions that also varied by departure time. The simulator consisted of a decision screen where users were shown an intersection map and information concerning traffic conditions on each available route choice. Guidance, if available, was provided via a flashing arrow on the recommended route choice. The simulator was successful in achieving its aim, but its principal drawback was that the simulation experience did not resemble real-world conditions. Information concerning traffic conditions was provided for every link, which even today is not a reality. Participants were also given an idea of the number of people before them chose each route, which is information that is rarely available to motorists. Nonetheless, IGOR was a significant first step in the field.

One of the first model-backed travel simulators was developed by Chen and Mahmassani (5). The Dynasmart mesoscopic traffic flow simulator was used as the back-end to provide link travel times to users on demand, in real time. Furthermore, users were able to participate simultaneously, thereby mutually affecting conditions on the small artificial network. A message generator was further used to provide traffic information commensurate with network conditions. Since the number of concurrent users was limited to 100 people, the traffic flow simulator used over 10,000 additional vehicles to simulate traffic conditions. The major feature of this work was

the realistic simulation network effects. However, the small pool of 'real' users compared to the 10,000+ simulated vehicles limited the effects of interactions between participants. Furthermore, the simulation occurs in real time, meaning a single trip requires about 20 minutes. Without the normal stimulus of real-life driving, this may lead to participant boredom, and in the case of repeated trips, participant fatigue. Lastly, the user interface again did not approximate the driving task very well, and ATIS information was typically provided in the form of exact travel times that gave no indication of travel time reliability.

A couple of investigations have been performed regarding the provision of traffic information from different sources. Koutsopoulos et al. (6) developed a simulator with a goal of making the driving task more realistic, which they accomplished via having the participant use computer keys to keep a small ball inside the outline of the traveling vehicle. The simulator appears to be unique in providing radio information in addition to VMS messages. Unfortunately, these radio messages were displayed visually in a manner similar to VMS messages, only with an accompanying audio symbol. Although this was likely due to limitations of computer hardware at the time, it is questionable whether users truly distinguished between sources of information provided. Emmerink et al. (7) carefully analyzed driver behavior in response to radio and VMS traffic information via mail surveys. Although this work was not related to the development of a traffic simulator, it is nonetheless important since it represents one of the first in-depth studies of driver behavior and response in the presence of information from multiple sources.

Adler et al. (8) produced the FASTCARS traffic simulator as a means of testing their theories of route choice decision making based upon conflict arousal and resolution. The entire trip-making process is simulated, including pre-trip planning and ranking of stated objectives for travel (minimize delay, travel time, stops, distance, or decisions). Users are instructed to maximize their score (a weighted average of their rankings) by driving through the network; using a keyboard, they are capable of changing lanes and performing turning movements to select a new link. Traffic information is provided via static roadway signs as well as ATIS information via VMS, highway advisory radio, and in-vehicle navigation systems. Radio and in-vehicle navigation information is only provided when a user requests it and is subject to score penalties for use. This project represents the first simulator to use audible simulated radio messages. However, it is unfortunate that users are penalized for radio information, since radio messages are generally provided to the public at no cost.

In the development of VLADIMIR, Bonsall et al. (9) made considerable improvements over their previous work. This simulator provided participants with a user interface that more faithfully represents reality, simulating the view from the driver's seat. Congestion is indicated by superimposing a vehicle outline over the image which indicates whether traffic is Light, Medium, or Heavy. Traffic information was provided via a Variable Message Sign (VMS) which is superimposed over the traffic scene image. Route travel time is indicated via the rate of image updates along the route, as well as the speedometer and an audible engine sound. Deliberation time at each decision point is limited to a reasonable amount via the sounding of a horn if the user is taking too long. VLADIMIR has been successfully demonstrated in several projects throughout Europe, demonstrating flexibility. It is also well suited for large networks and is very customizable in terms of information provision. Perhaps the only drawback is that participants must perform the study in a laboratory environment.

One of the first investigations into utilizing Internet technologies was performed by Kraan et al. (10), who studied traveler behavior in the context of shopping trips. The survey consisted of collecting pre-trip information, simulation of two trips, and a post-trip survey of preferences and factors affecting decision-making. The survey was implemented in Javascript, and it demonstrated that the Internet can be used as a medium for collection of travel behavior data. Although this was

one of the first simulators to explicitly examine a trip purpose other than work trips, it is questionable whether drivers would seek such ATIS information for decidedly leisure trips. Furthermore, the trip simulation did not attempt to represent life-like conditions, providing no simulation of the driving experience at all.

Ozbay et al. (11) studied the use of stochastic learning automata (SLA) to account for day-to-day learning in driver route choice behavior. An Internet Route Choice Simulator (IRCS) was developed to aid in calibration of their model. The IRCS was implemented in Java, which requires users to install a Java runtime environment in order to access the applet. Although the simulator was successful in collecting data for their work, it is evident that the simulator was not designed to be applied to anything other than data collection for their SLA model. As with the previously discussed Internet-based simulator, no effort was made to approximate the driving process. The interface consisted solely of a few background and demographic questions and a network view. Furthermore, travel information was provided only in the form of travel times, and it appears that users were only able to choose between two routes.

Historical congestion data and a realistic network were used by Abdel-Aty and Abdalla (12) to develop the Orlando Transportation Experimental Simulation Program (OTESP), a MS Windows-based simulation program. Delay from congestion, weather, and incidents were included in the simulation, as well as area toll booths. Advice on the shortest travel-time path was provided to a subset of users. A unique advantage of this simulator was the inclusion of bus routes, thus becoming one of few multi-modal route choice simulators. The simulator has clear user interface consisting largely of a network map which was easy to understand. However, images simulating the driving experience were not employed, again divorcing participants from their personal experience to some degree.

Chen and Jovanis (13) developed yet another PC-based travel simulator in which they examined driver learning and compliance with route guidance. They used a small artificial network composed of a freeway and two arterial streets connected via multiple local streets. The authors emphasized correction of the repeated measurements problem since participants were expected to perform multiple trips. While their study did include pre-trip guidance, they did not investigate effects related to difference trip purposes or departure times. Also, the user interface was implemented in DOS, which made it appear quite antiquated compared even to works done several years earlier. This made the interface difficult to understand as it did not resemble the usual driving experience.

Koutsopoulos et al. (1) produced a detailed review and evaluation of all traffic simulators developed or in development as of 1995. Although the projects reviewed are dated, the review criteria they established are clearly still relevant today. Some of these criteria will be examined later in the discussion section. Lappin and Bottom (14) performed an exhaustive review of all literature concerning traveler response to information in 2001. Although the scope of that review is larger than that of this paper, it serves as a clear indication of the state of the art regarding traveler information entering the 21st century. Finally, Abdel-Aty and Abdalla (15) provide a more recent and quite useful comparison table overview of travel simulators.

The travel simulator developed in this paper bears similarities to many of the simulators discussed here. However, this simulator improves on existing work by implementing a truly interactive Internet based simulation which aims to represent the driving task and various traffic information sources as faithfully as possible. The current implementation employs only VMS and radio data; nevertheless, the system is easily extensible to provide alternative forms of ATIS information, such as GPS Navigation, and text message (SMS) traffic alerts.

EXPERIMENTAL DESIGN

The survey tool developed in this study aims to investigate driver compliance with traffic information from multiple sources. The user interface was particularly inspired by the work of Bonsall et al (9). In contrast to the simulators reviewed previously, the travel simulator described in this paper is web-based. Therefore, participants are able to drive the simulator from any computer capable of browsing the Internet (provided certain conditions are met, as explained later).

A web-based survey can offer many advantages over traditional PC-program based solutions. A primary advantage is cost – traditional simulators require participants to travel to a laboratory or other location where the software is installed. This requires some planning and effort for the participant, so some level of compensation is usually necessary to attract a sufficient population. Those participants must also be supervised, which adds to personnel costs. Alternatively, Internet-based surveys allow participants to complete the survey wherever they choose. Moreover, an Internet survey offers greater convenience and flexibility, even allowing participants to pause and resume the survey at a later time.

This section is separated into a discussion of the various conceptual and computational elements used to construct the simulator.

Travel Network

In this study, a simulated trip to work is examined for the collection of driver behavior data. The simulated trip consists of driving from the origin in southeast Stockholm (Nacka/Värmdö) to the destination, KTH (Kungliga Tekniska Höskolan, or the Royal Institute of Technology). Although there are many potential routes between these two locations, only a subset of links and nodes were chosen. Those chosen were based on how reasonable they were based upon information gained from focus group meetings with KTH employees who frequently drive to work from the southeast of Stockholm. Figure 1 illustrates the resulting network consists of 46 links (black lines) and 24 nodes (non-lettered blue pin markers). The origin node is indicated by a green start pin, while the destination node is marked with a red stop pin.

Incidents and Traffic Information

During travel simulation, users may encounter one of four types of incidents. The incidents vary in location and severity, and are indicated in Figure 1 by letter markers:

- A. Forum Nacka (Värmdöleden) – traffic accident, left lane blocked
- B. Danviksbron – technical problem, bridge gates locked
- C. Stadsgårdsleden – lost cargo, one lane closed
- D. Centralbron – vehicle fire, two lanes closed

Each incident has traffic messages associated with it. In this study, two forms of traffic information are available – simulated radio messages from Radio Stockholm, and short messages to be displayed via VMS. Since there are no real VMS installations at any of the decision points in the network, the messages are superimposed on the image representing the view from the driver's seat. This traffic information is provided at certain nodes preceding the incident location. Incidents A and B occur early in the simulated trip; information for these incidents is provided only once during a trip. Incidents C and D, however, occur later in the trip and may be shown twice during a given trip. If information about an incident is provided a second time, the information differs from the first message to reflect any change in the incident condition that may have occurred during the resulting passage of time.

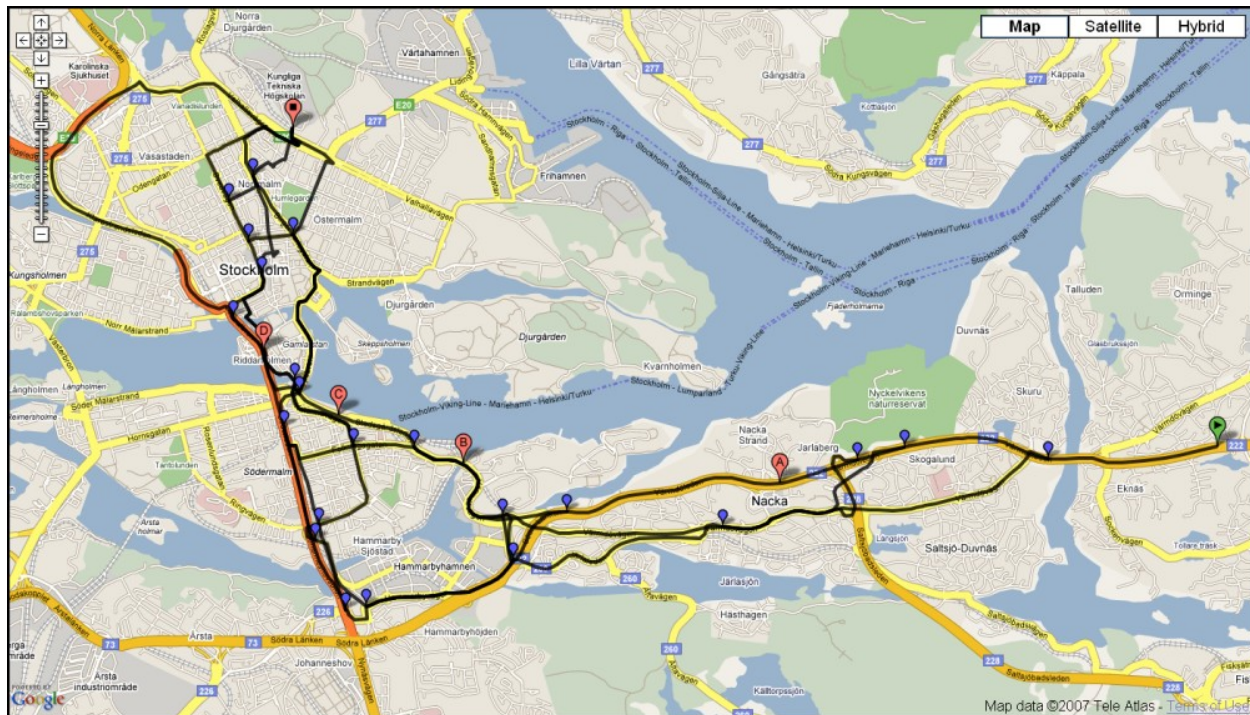


FIGURE 1 The study network.

Decision Presentation

When the user arrives at a decision point between two or more routes, he or she is presented a screen illustrated in Figure 2. The predominant feature is an image representing the view from the driver's seat as one approaches the highway exit or roadway intersection. If incident information is available at the decision location, a simulated VMS displaying information is superimposed over the image in the upper left corner. A Google Map for navigation is provided in the upper right. This map displays a black line, representing the traveled path, and colored lines corresponding to each available route. A pin marks the location of the decision point. A sentence under the map details which road the user is driving on and asks which road he or she wishes to choose. Each choice is outlined in the color corresponding to the link on the map.

The black bar at the bottom of the image displays time information. The start time entered by the user is displayed on the left, and the normal arrival time for the trip is displayed some distance to the right. The colored bar between the two reference points represents the elapsed time since the departure time. As it approaches the normal arrival time, the color of the bar shifts from green to yellow and yellow to orange. When the elapsed time exceeds the normal arrival time, the bar turns red, indicating that the driver is late. Lastly, if radio information is available at the decision point, the radio message plays automatically and an audio symbol appears to the right of the time bar to indicate that a message is playing.

Driving Simulation

The driving task is simulated whenever the user is traveling along a link, illustrated in Figure 3. Although similar to the decision screen, the driving screen has a few notable differences. First, in place of the map showing the user's location, an analog clock is displayed to show the progression of time. A sentence under the clock describes which road the user is driving on and to where he or she is headed. Whenever driving after a decision where traffic information was provided, a question appears on the driving screen inquiring the user to estimate how much delay he or she

would have expected to have encountered if traveling on his or her normal route. Finally, the black bar at the bottom displays time information in the same manner as the decision screen. No traffic information (via VMS or radio) is presented when driving on a link.

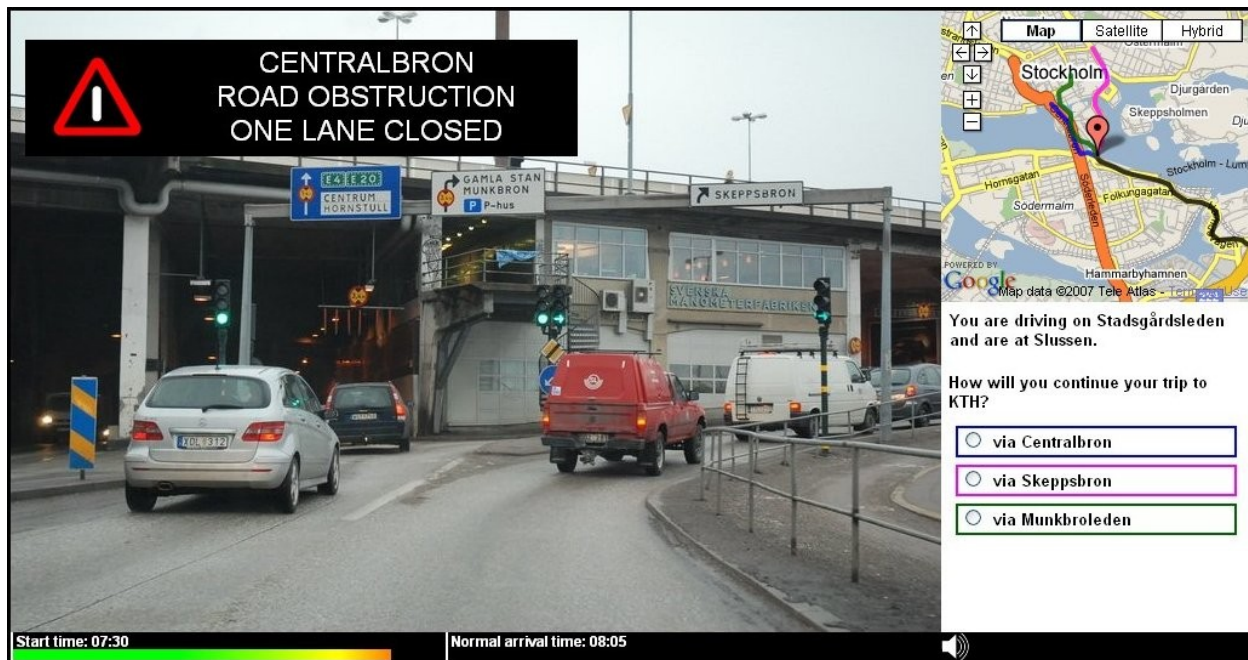


FIGURE 2 The simulated decision screen with VMS and audible radio information.

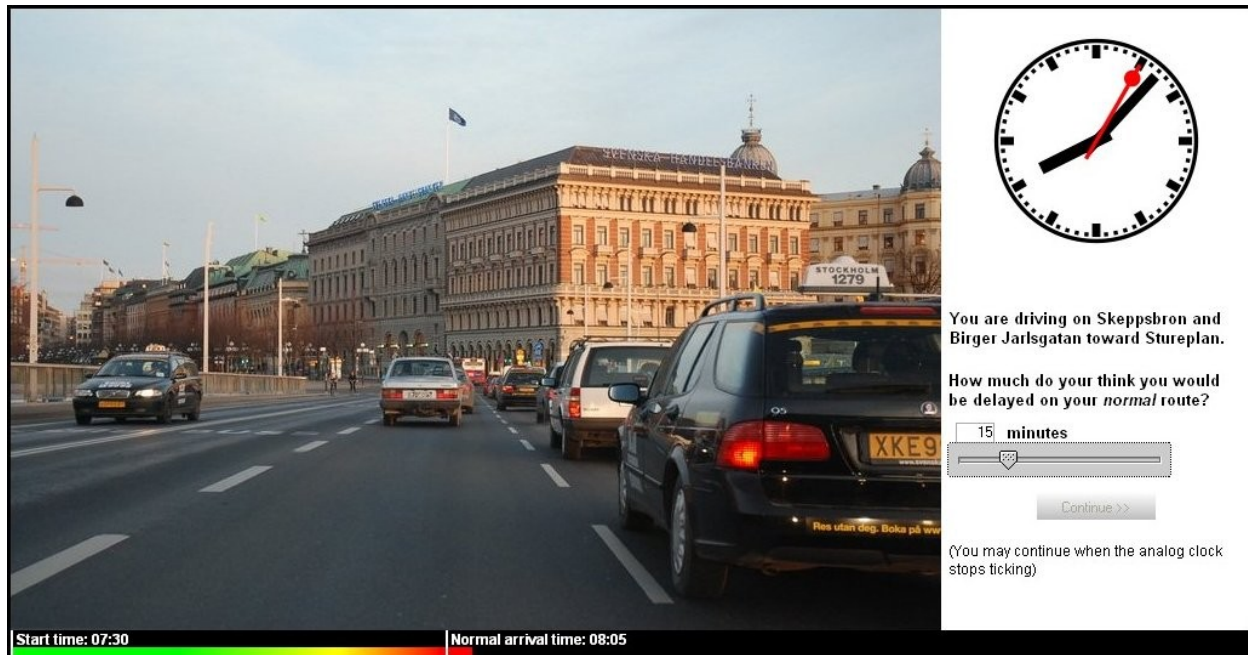


FIGURE 3 A view of a user driving along a route to the next decision point.

Driving simulation occurs at a rate of 15:1 to enable multiple trips through the simulator and to avoid participant fatigue. Thus, one simulated minute passes in four real seconds. Passage of time is represented by the ticking analog clock and updates to the colored time bar. Furthermore,

the traffic image is updated as the user progresses along the link. The number of images and the time interval between display of a new image is dependent on link travel time and encountered delay. Travel times for each link were obtained from travel times experienced while driving through the network to collect digital images of each link. These travel times are increased by 50% when an incident has occurred and 100% when the route is directly affected by the incident. For the purposes of the current study, these simplistic travel times were acceptable. However, it is expected they will be replaced by model-backed travel times in future implementations.

Pre-trip Data Collection

When a user starts, he or she is asked to complete several background questions regarding how often one drives to work, one's familiarity with the road network, and the time of departure. The user then selects his or her normal route to work by starting at the origin and selecting a road at each encountered node via the decision presentation screen previously discussed. This normal route is important since users will only encounter incidents which occur on the normal route and it is the basis for the normal arrival time at the destination. It is also necessary to determine whether the user has departed from the normal route during simulation. The user then receives instructions regarding the simulated driving task and a test sound to see if the user is able to receive radio messages. Table 2 describes the pre-trip data collected.

TABLE 1 Collected Pre-trip Data Description

Variable Name	Description	Possible Values, Type, or Example
drive_freq	How often the user drives to work	0: Never 1: Seldom 2: Once per month 3: Once per week 4: Several days a week or more
familiarity	User familiarity with the network	0: Not at all familiar 1: Somewhat familiar 2: Fairly familiar 3: Quite familiar 4: Very familiar
default_path	Node-to-node default route	Ex: 1:2:3:4:6:13:15:21:24
start_time	The user's departure time	TIME
normal_tt	Normal travel time on the default path in seconds	NUMERIC
tt_quality	User assessment of the normal travel time	-1: Seems too short 0: Seems reasonable 1: Seems too long

Trip Simulation

Once all pre-trip information is collected, the user may begin making trips in the simulator. Trips consist of traveling through the network from origin to destination via alternating driving and decision screens. Each trip is assigned an incident chosen from the incidents available on the user's normal route to KTH. Furthermore, three levels of traffic information are available – VMS only, radio only, or both VMS and radio. The incident and information provided for the first user's trip is chosen pseudo-randomly based on a modulus of the user's account id. This is done to ensure that no particular incident and information type are over-represented should users not complete all trip and information combinations.

At the end of each trip, the user is informed of how early or late he or she arrived and is given an opportunity to provide feedback about their experience or comments to the developers. The user is then encouraged to perform additional trips, in which the simulated incident and information type(s) are adjusted until all permutations have been simulated. At this point, the user may continue to make additional trips, but these trips are flagged as 'extra' trips since the situation has been encountered before. The data collected from each trip is detailed in Table 2.

TABLE 2 Collected Trip Data Description

Variable Name	Description	Possible Values, Type, or Example
trip_number	Sequential user trip number	NUMERIC
extra	Indicates if the user has driven this trip previously	BOOLEAN
condition	Simulated incident name	Centralbron
vms_info	Indicates if VMS information is provided	BOOLEAN
radio_info	Indicates if radio messages are provided	BOOLEAN
node_path	Node-to-node route	Ex: 1:2:3:4:6:9:11:12:18:19:20:22:24
actual_tt	Trip travel time in seconds	NUMERIC
divert_node	Node number where the user diverted from the normal route	0: User did not divert from normal route Otherwise: NUMERIC
divert_time	Elapsed travel time in seconds when the user diverted from the default route	0: User did not divert from normal route Otherwise: NUMERIC
total_user_delay	User assessed delay in seconds after receiving traffic information	NUMERIC

Since the survey is still under development, there are no results to report. A study investigating user response to VMS and radio traffic information is beginning in Stockholm in August 2007. In that study, over 1000 people will be invited to participate by driving through the simulator as many times as they wish under the study period. The 1000 participants were selected from a list of employees at KTH and Stockholms Universitet just to the north of KTH. Those chosen live in the area southeast of Stockholm and therefore should have some familiarity with the network used in this study. The data resulting from this study will be analyzed and the results will be presented in future papers. In addition, the results will be used to improve the route-choice and diversion models in the Mezzo mesoscopic simulator (16,17).

Computing Requirements

As mentioned previously, any user with access to the Internet should in principle be capable of participating in the survey. However, since the survey involves the presentation of large amounts of image data, a broadband connection is recommended. Javascript is also required in order to participate, as the interactive features of the simulator depend on Javascript to function properly. Finally, although not strictly a requirement, Adobe Flash is necessary if participants wish to receive radio traffic information. The simulator has been developed to work with most modern browsers, including Internet Explorer (version 5.5+), Mozilla Firefox (version 1.5+), and Safari (version 1.3+).

Technical Implementation Details

The simulation was programmed using the Ruby on Rails web application framework. This framework promotes the MVC (Model-View-Controller) programming paradigm, which separates

model and program logic from the presentational aspects. The static content (images, Javascript files, and CSS style sheets) are served by an Apache web server, while the dynamic portions are served by a Mongrel Cluster (a cluster of web servers particularly suited for interpreting and serving ruby applications) balanced via Apache's load balancer. Network data and participant results are stored in a MySQL database on the same server. Gettext was used to translate the application to other languages. The application interface is currently available in only English and Swedish, but is easily extensible to other languages by the translation of a single message catalog. The address of the survey is <http://ruttval.ctr.kth.se/>.

DISCUSSION

As indicated by Koutsopoulos et al. (1), the principal drawback to travel simulators is that they produce stated preference (SP) data, which is subject to biases resulting from the travelers' behavior being observed in a hypothetical situation rather than in reality. They conclude that many of these biases may be mitigated by designing a simulator that represents real-world conditions, but caution against making the simulator too game-like. In the following sections the simulator developed in this study is evaluated according to the recommendations proposed by Koutsopoulos et al. (1):

Scope of Data Collected

Currently, awareness and access to ATIS information is not collected beyond a cursory question regarding network knowledge. Although this information was not deemed necessary for the initial study of Stockholm, it is easy to add such questions develop an extended pre-trip survey. In fact, a separate stated preference study for another portion of the project already includes a number of access questions. The nature of web-based surveys also makes the addition of questions a trivial task. This study also assumed VMS and radio availability to all drivers since those forms of information are available at no cost. However, in future investigations regarding alternative ATIS sources like text messaging (SMS-info) or GPS navigational aids, these sources may easily be provided for some simulated cost while remaining endogenous to the system. Finally, this simulator does not support multi-modal options in the current implementation. Again, future studies involving likelihood to switch mode may easily be implemented by simulating transit links in the network.

Quality of Data Collected

Travel Simulator Design

This simulator employs the recommended "windshield-view" representation of the network and strives to provide traffic information in the same manner as is encountered in real life. The images currently in use represent morning conditions since the trip to work is being investigated. Alternative weather conditions may be simulated merely by acquiring images for each weather type. This simulator is also capable of simulating any real network, with the work required to implement the map guide being greatly simplified by the use of Google Maps. Artificial networks may also be implemented, provided artificial maps are produced. In terms of human factors, this simulator performs well, only providing ATIS at certain locations and simplifying the user interface as much as possible.

Experimental Design

The study described above utilizes employees of KTH and Stockholms Universitet. The employee lists included staff and service people as well as professors, so it is not anticipated that there should

be any bias with respect to gender, age, income, etc. Confounding effects of participant unfamiliarity with the simulated driving task may be addressed by splitting the results into two populations based upon a trip number corresponding to where users may be assumed to be proficient. The current study specifically examines work trips, so any future studies would require consideration of any situational constraints that would not be represented in alternative trip purposes. No attempt is currently being made to provide post-trip results detailing overall network conditions. In situations where the incident information is not always reliable, an overview of any 'mistakes' the user made in judgment, or purposeful inaccurate information provided by the simulator could be invaluable in combating justification bias. Alternatively, it is not always evident in the real world whether traffic information is reliable or not, and people are not always aware of any judgment errors they may have made.

Real-world factors influencing decision making are currently implemented entirely in the passage of time. Users are 'punished' for poor decisions or suffer from inaccurate information by a longer link traversal time, which ultimately results in arriving at the destination late. A conscious decision was made to not reward drivers in order to avoid the simulation being misinterpreted as a game, thereby confounding the results. Nonetheless, the simulated driving task differs enough from real world experience that any insights into how to better approximate real life conditions would clearly benefit the simulator.

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Traveler behavior and response must continue to be studied in order to maximize the benefit of ATIS information. Travel simulators are a valuable tool to achieve this aim. This paper outlines the development of a new Internet-based travel simulator for route choice behavior. The simulator utilizes a windshield view and strives to accurately represent traffic information from multiple sources. The Internet-based approach has clear advantages in terms of user participation and data collection costs. Finally, the simulator meets many of the guidelines proposed by Koutsopoulos et al. (1).

Given the extensibility of the tool developed in this study, it is likely to be utilized in many future investigations. Such studies may include a deeper investigation of how pre-trip alternatives and decisions affect route choice, or investigations into the effect of message wording on route choice. A study of how decisions are made in the presence of contradictory, overlapping and/or updated traffic information would also be possible using this tool. Alternative ATIS sources such as GPS navigational aids and text-message alerts (SMS info) could also be added. A much more ambitious project would involve using a traffic simulation model to generate link travel times and network conditions by time of day on demand. Although certain elements will certainly require changes and customization, it is reasonable to expect that many studies will be able to easily build upon the existing base web application.

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