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Design of a Network and Travel Simulator: A Tool Box for the Analysis of Route Choice Behavior in the Presence of Information

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ABSTRACT

The application of advanced technology and its potential to alleviate a host of traffic related problems has spawned numerous research programs into the investigation of how advances in information technologies may be utilized to significantly alter traveler behavior. If real-time, accurate information on the characteristics of the travel environment can be provided to travelers prior to departure and while enroute, will behavior be altered in such a way as to improve the overall characteristics of the travel environment? In order to accurately model the macro-level effects of Advanced Traveler Information Systems (ATIS), the micro-level effects of these systems on individual driver behavior must be analyzed and understood. The use of computer simulation and modeling is being utilized as a data collection tool to study advanced traveler devices to supplement real operational systems and as a cost effective alternative to field studies (Bonsall, 1990, Adler, 1993, McNally, 1993). Researchers at the University of California at Davis are utilizing PC based computer simulation to study the effects of information on individuals' route choice behavior and learning. Previous research utilized a simplistic binary route choice simulation to collect sequential data on subjects decisions (Vaughn et al., 1993, Yang et al., 1993). Building on the efforts from this previous simulation, a new set of experiments utilizes an expanded traffic network and provides various levels of information content to the subjects. This framework allows for investigation of both pre-trip and enroute decision behavior and captures the effect of different levels of information on route choice and

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diversion. In this series of experiments further investigation of drivers learning and adaptive processes are also explored.

INTRODUCTION

The simulation is an interactive PC program running on a DOS based platform. The screen display is composed of three main windows: a network window, an information window, and an instruction window. The network window displays a hypothetical traffic network, composed of three primary routes from an origin to a destination. The travel environment is generated by a stochastic assignment of travel speeds and stop delays to the network links and nodes. A random incident generator is used to assign an incident of random severity to the network for each travel day. The information and instruction windows are used to simulate an in-vehicle information system. A structured in-laboratory simulation experiment has been designed utilizing different levels of information as experimental treatments. The simulation experiment is currently scheduled to take place in March of 1994 utilizing commuters from the Sacramento California region as test subjects.

The program is designed to be as self explanatory as possible with built in self paced instructions. The program also has an experimentation phase where subjects are allowed to make preliminary trials on the system and request help until they reach a point of familiarity with the system and then can proceed to the actual simulation. Also an interface is provided to allow the experimenter to set up the desired experimental conditions which will be in effect for each subject. In the previous experiments this consisted of a numbering scheme which was used to identify all the possible combinations of treatments. A similar scheme has been developed for this simulation and all data will be stored in a specific directory in a separate file for each subject identified by this number.

TRAFFIC NETWORK

The network window displays a hypothetical traffic network. The network is composed of three primary routes from an origin to a destination. The primary routes are composed of a freeway route and two arterial routes, which are cross connected with a series of surface streets creating a network of 34 roadway links and 23 intersections (or potential decision points) (see Figure 1 for network configuration). The links running from node 2 to node 22 make up the freeway route, and the links running from nodes 3 to 23 and from 4 to 24 make up the two arterial routes (1st and 2nd streets). While this network is still simplistic in comparison to the real traffic environment it is a considerable step up in complexity from the two-link, two-node traffic network utilized in the first set of learning experiments and may adequately represent routing alternatives which are avialable to many commuters.

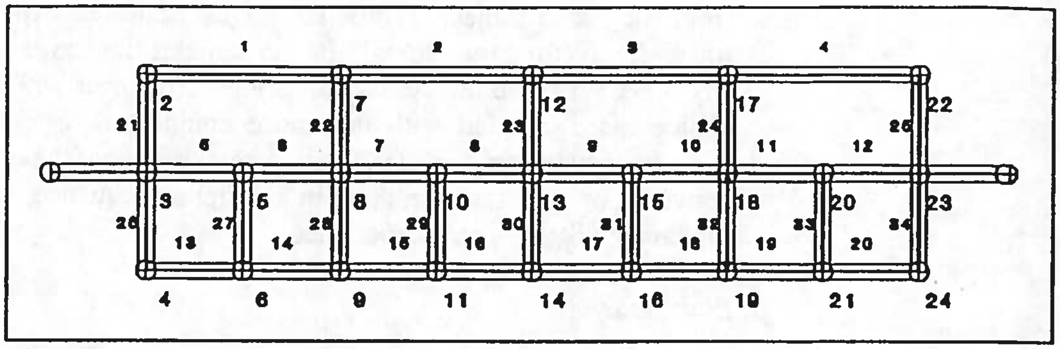

Figure 1: Simulation Network

The network window is animated in that the simulated vehicle movements will take place within this window. A simulated vehicle (cursor) will move through the network in response to decision inputs by the subject. Control commands will be input via the key board to indicate desired turning movements. The simulation is currently designed with a 1:30 time scale (1 minute real time = 2 seconds simulated time).

Consider one of the freeway links, the program has been configured such that each freeway link is 10 characters in length. The movement is generated by having the cursor move from character to character along the link. The time the cursor stays at each character location is determined by the delay setting of the link. This delay setting is currently in 1/1000 second increments. Thus if the delay setting on a freeway link is 1000, then the cursor will move from character to character at a rate of once per second. Assuming one freeway link represents 5 miles this represents a 20 mile freeway segment and each character position represents .5 miles. In the real world, assuming a travel speed of 30 mph, it would take 1 min to traverse .5 miles thus with a 1:30 time scale, it takes 2 seconds to traverse the .5 mile character position. Also, if the overall average freeway route speed were 30 mph, it would take 1 minute and 20 seconds to traverse the 4 freeway links.

A simple formula converts the link speeds to segment delay values:

link delay = character length(miles)*time scale*60s/min*60min/hr*1000/speed(in mph) = 60000/speed (mph).

For example if a freeway link speed is 50 mph, then the delay assignment is 1200 or 1.2 seconds per character movement and the 5 mile link would be traversed in 12 seconds of simulator time.

The intent within this simulation is to present the subjects with a sequence of travel days. To accomplish this a series of network characteristics which will be the basis for the daily travel experiences encountered by the subjects have been generated. Additionally, because the focus is on the effects of the information, we also want to filter out as much variability due to the network as possible. To accomplish this, the sequentially generated travel days are dynamic across the sequence, but static from subject to subject. Thus, the travel conditions experienced by subject #1 on travel day 6 (for example) will be the same as the travel conditions experienced by any other subject on travel day 6. Some differences will be experienced which are choice-based, in that with this more complex network for a given travel day, subjects may not traverse (and therefore experience) the exact same segments of the network, or may traverse them in a different sequence, and therefore may have a fundamentally different experience.

Link Delay

The simulated network characteristics are pre-generated and stored in a network data file. This data file will contain all of the network characteristics identified by travel day and link or node number. The simulation program will then simply read this data file to create the travel environment for each day. A subroutine has been developed to create and write this file. The primary network characteristic will be delay. The delay will be of two forms, congestion delay experienced on a link, and stop delay experienced at nodes or intersections. Additionally, the congestion delay will be of two types, pure congestion, and incident caused congestion. On roadway links, the delay assigned will be inversely proportional to the travel speed on that link for that day. When an incident has been assigned to occur on a particular link, the delay assigned to that link will be elevated due to the incident.

The use of the normal distribution is suggested (A.D. May, 1990) to represent speed distributions on roadway links. For this simulation the network characteristic subroutine creates normally distributed link speeds for each link in the network. It is assumed that the freeway is congested 40 percent of the time and in the simulation, the freeway is randomly assigned to be in a congested state at this level. The freeway links are N(μ=35mph, σ=7mph) on congested days and are N(μ=45mph, σ=5mph) on uncongested days, 1st street is N(μ=35mph, σ=5mph) and 2nd street is N(μ=40mph, σ=2mph) and side streets are N(μ=25mph, σ=1mph). This creates a scenario within the network where the three primary routes through the network have the similar mean speeds on average, but the variance in travel speed is much greater on the freeway than on the arterials and the surface streets have lower mean speeds, but experience little variation. For the normal distribution, approximately 95% of the observations will be between $\pm 2\sigma$. This means that typical speeds will range from 15 mph to 55 mph on freeway links, 23 mph to 47 mph on arterials and from 23 mph to 27 mph on surface streets. The speed distributions have been right truncated at the free flow or design speed of the links such that the maximum speed is 55 mph on freeway links, 45 mph on arterials and 30 mph on surface streets. The subroutine converts the speed assignments to units of delay which the program uses to simulate movement in the network.

Incident Delay

For this simulation it will be assumed that it is not unreasonable to expect at least one incident to occur within the network on each simulated day. It is also reasonable to assume that incidents are more likely to occur on the freeway and arterial links than on the surface streets. For this simulation, we will assume that the probability of an accident occurring on a given travel day is 1.0 and that the probability of the accident being on the freeway or arterial links is 4/5 and the probability of being on the surface streets is 1/5. Then,

P(incident on freeway route | it is on freeway or arterial) = 2/3
P(incident on arterial route 1 or 2 | it is on freeway or arterial) = 1/3

(i.e. twice as likely to occur on the freeway as opposed to the arterials.)

Then,
P(incident is on a particular freeway link | incident on freeway route) =
1/(number of freeway links) = 1/4

P(incident is on a particular arterial link | incident on arterial route 1 or 2) =
1/(number of arterial links) = 1/16

P(incident is on a particular surface link | incident is on surface streets) =
1/(number of surface links) = 1/14

Then,
Total probability of the incident occurring on a specific freeway link =
1/4 * 2/3 * 4/5 = 2/15.

Total probability of the incident occurring on a specific arterial link =
1/16 * 1/3 * 4/5 = 1/60.

Total probability of the incident occurring on a specific surface link =
1/14 * 1/5 = 1/70.

Incidents occurring on the network are randomly assigned as being either moderate or severe in nature. Links with incidents assigned have their link speed assignments reset to 15 mph for severe incidents and 20 mph for moderate incidents. For each incident one of three incident types is also randomly assigned. Moderate incidents are assigned as either Accident, Stalled Vehicle, or Maintenance while severe incidents are assigned as Injury Accident, Truck Accident, or Maintenance Lane Closed.

Stop Delay

From the first set of learning experiments, the effects of stop delay had significant effects on driver behavior (Vaughn et al. 1993). The compliance with advice was significantly lower in conditions where subjects experienced stop delay primarily due to subjects rejection of advice to take the route with stops. These results suggest significant behavioral differences in response to stop delay versus congestion (or moving delay). Within this simulation we will again incorporate the effects of stop delay in a more realistic manner. Additionally, because this is a simulated network, stops become the only route (or link) specific attribute (besides speed or delay).

Stop delay will occur as the result of either stop signs or signalized intersections. In figure 1, nodes 8, 9, 13, 14, 18, and 19 are signalized intersections, nodes 5, 6, 10, 11, 15, 16, 20 and 21 have stop signs only on the surface street approaches. Nodes 2, 7, 12, 17 and 22 represent freeway on/off ramps and are not assigned stop delay in the simulation. At stop sign locations the vehicle tracking cursor will stop for an appropriate amount of time, but at signals, stops are only required when the light is red. Stop signs have been assigned a delay value of 2 seconds for right turn movements and 3 seconds for left turn movements giving a greater penalty for the left turns. Within the simulation a 50% probability of the light being encountered as red is used for every signal encountered . In this scenario, stop delay is mandatory at all stop signs, and stops at signals will be encountered approximately 50% of the time when traversing the network.

As currently designed, the network characteristic data file is generated once for each trial day reflecting a static information situation. To move to a dynamic information system, several files (say 4) could be generated for each trial day then the initial information provided would come from the first file and at some fixed time into the trial, the information could be refreshed or updated from the second table, likewise for a third table and so on for what ever seems appropriate depending on the total travel time in the network and a reasonable refresh rate. Within a scenario of this type we may want to update everything except incident information and assume that the incident durations will be longer than the total travel time in the network (this doesn't seem unreasonable as the network is not that large but it may also be interesting to see the effects of clearing an incident).

EXPERIMENTAL DESIGN

Factorial experiments are typically used in production process environments where the variability between the units of analysis are generally small. In behavioral experiments where the experimental units are people, individual difference can be great due to differences in background, education, life experiences, etc. In this case, between subject variability can become large resulting in difficulty in detecting real differences between treatments. To deal with this problem, often repeated observations are required for each treatment combination. Assuming we can reasonable recruit and test at least 100 subjects, then the 2^{7-3} fractional factorial design would allow for 6 subjects within each treatment combination.

The experimental design selected for this simulation study is a 1/4 fraction of a 2^7 factorial design. With two levels for each factor, a full factorial design would require a minimum of $2^7 = 128$ runs. A one-quarter fraction of this design can be used requiring a minimum of only 32 runs and if 3-way and higher interactions are assumed to be negligible, then all of the main effects are estimable and 15 of the 21 2-way interactions are also estimable (Montgomery, 1991). With three subjects per design block, 96 subjects are required.

The experiment will apply four information treatments and will use 3 blocking factors to make up the seven experimental treatments. The information treatments are labeled A through D and the blocking factors are E through G. All treatments have two levels and are described below:

A. Incident with description. Red Icon displayed at the location of a severe incident, yellow Icon displayed at the location of a moderate incident. Also in the information window, display textually the location and classification of the incident for example: "Sever injury accident on First Street between F st. and G st." (on/off)

B. En-route Guidance. Graphical arrows indicating advised turning movements and textual description of advice. (on/off)

C. Pre-trip Guidance. Minimum path displayed at beginning of trip with an estimate of the travel time on the path for that day. (on/off)

D. Congestion Information. Color coded links for moderate and severely congested links with green indicating normal congestion, yellow indicating moderate congestion and red indicating severe congestion. (on/off)

Three blocking factors:

E. Gender, male/female.
F. Age, young/old.
G. Education, high/low.

Estimable effects:

Main effects: A,B,C,D,E,F,G
Two-way interactions: AB,AC,AD,AE,AF,AG,BC,BD,BE,BF,BG,CD,DE,DF,DG
Aliased two-way interactions: CE=FG, CF=EG, CG=EF

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