A Travel Simulator for Collecting Data on Driver Response to Graphical Route Information Panel

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Abstract

A recent attempt to enhance traveler information services and alleviate congestion is by the use of graphical route information panel (GRIP). This paper proposes a travel simulator for collecting behavioral data on driver response to GRIP. The traffic network conditions and GRIP information are driven by an extended version of the validated high-order continuum model METANET, thus enhancing the realism of the hypothetical travel scenario provided by the simulator. The methodology for simulator design is presented. A prototype simulator was developed.

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Keyword: Travel simulator; graphical route information panel; route choice response; high-order continuum model; stated preference;

1. Introduction

Internationally, a recent attempt to enhance traveler information service and alleviate congestion is to use graphical route information panel (GRIP) (for example, Hirokazu and Mitsuru, 2000; Schönfeld et al., 2000; Alkim and Schenk, 2001; Dicke and Brookhuis, 2008; Richards et al., 2004; Kloot, 1999; Lai, 2012; Aitken et al., 2012; Gan et al., 2006; Gan, 2010). GRIP, a new type of variable message sign (VMS), uses graphical information, i.e. colour-coded level of service (LOS), to represent current traffic conditions of a particular area within the road network to convey traffic messages instead of text. It assists drivers in making more informed route choice. In China, the interest in utilizing GRIPs now is very high. GRIP has been widely used in big cities such as Shanghai, Beijing, Ningbo and Hangzhou. Advantages of GRIP have been well-recognized in literature. Fig. 1 presents a real GRIP in Shanghai expressway management (Gan et al., 2006; Gan, 2010).

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Understanding driver response to GRIP is very important for GRIP operations design and benefits evaluation. Such understanding is usually based on developing models that capture driver behaviour in the presence of GRIP information. However, data that can assist model development are not readily available (e.g. Koutsopoulos and Polydoropoulou, 1995). The difficulties in collecting real behavioural data on individual driver's response to GRIP are mainly due to: (1) existing traffic monitoring systems (e.g. loop detector based systems) usually can not cover the entire network and some roads influenced by GRIP are not monitored. Moreover they are not able to obtain individual-level data on GRIP response. (2) the history of GRIP application are relatively short, thus traffic data that are useful for eliciting comprehensive insights into GRIP response are not sufficient. (3) effects of GRIP usually are significant only under unexpected events (e.g. incidents). But it is unsafe to do real-world experiments to collect GIRP response data under unexpected events. For these above reasons, the stated preference (SP) data on driver response to GRIP are crucially needed for model development. SP data indicate how travellers behave in hypothetical travel scenarios. SP data can be collected by either various forms of surveys (mail-back, interview, computer-based, internet-based, etc.) or more sophisticated experiments using travel simulators. Travel simulators are more efficient than surveys regarding ease of use, realism of hypothetical travel scenario and flexibility of question presentation, although developing travel simulators may be a non-trivial task. The term ‘travel simulator’ should not be confused with ‘driving simulator’. Driving simulator is mainly applied in vehicle engineering and traffic safety (e.g. Koutsopoulos and Polydoropoulou, 1995).

This paper proposes a travel simulator for collecting behavioral data on driver response to GRIP. Currently, there are few literatures reporting travel simulators that are dedicated to collecting GRIP response data. However, there have been studies of travel simulators for collecting behavioral data on driver response to other types of traffic information, e.g. VMS text message, radio traffic information and in-vehicle guidance (e.g. Koutsopoulos and Polydoropoulou, 1995; Adler et al., 1993; Chen and Mahmassani, 1993; Koutsopoulos and Lotan, 1994; Bonsall et al., 1997; Avery et al., 2008; Bonsall and Parry, 1991; Abdel-Aty and Abdalla, 2006; Chorus and Molin, 2007). Table 1 summarizes some previous travel simulators for behavioral data collection and our GRIP-oriented travel simulator, which reflects difference between our work and previous studies.

Moreover, benefiting from recent advancement of traffic flow theories, this study, in contrast to the research team of Mahmassani who used a linear traffic flow model (modified Greenshield model) in their simulator, used a high-order continuum model to describe freeway traffic flow more accurately and enhance the realism of the hypothetical travel scenario provided by the simulator.

| simulators                  | Feature a: Traffic condition/information driven by traffic model? | Feature b: Choice dimension | Feature c: ‘Driving’ task considered? | Feature d: GRIP considered? |
|-----------------------------|---------------------------------------------------------------|----------------------------|--------------------------------------|-----------------------------|
| Adler et al., 1993          | N                                                            | R, D                       | N                                    | N                           |
| Chen and Mahmassani, 1993   | Y                                                            | R, D                       | N                                    | N                           |
| Koutsopoulos and Lotan, 1994| N                                                            | R                          | Y                                    | N                           |
The remaining of this paper is organized as follows. First, the design of the GRIP oriented travel simulator is presented. Then, a prototype travel simulator is presented. Last, concluding remarks are given.

2. Design methodology of GRIP oriented Travel Simulator

2.1. General Description

The simulator is a traffic flow model based route choice simulator, say, the network traffic condition that a subject encounters and the GRIP information he/she receives while travelling are derived by the traffic flow model. The author takes the advantage of the recent advancement of traffic flow theory to use the validated high-order continuum model METANET (e.g. Kotsialos et al., 2002; Messmer & Papageorgiou, 1990) as the traffic network simulation model, but we extended METANET to model freeway behavior more realistically under incident circumstances, for better describing the evolution of network traffic flows.

The operational structure of the simulator is presented in Fig. 2. The simulator experiment is conducted through interaction between the subject (human) and the simulator (computer). The subject is engaged in a hypothetical journey and “drives” in the simulated network and makes route choice decisions while encountering GRIPs. The simulator automatically records driver response throughout the journey.

![Fig. 2. the operational structure for the GRIP-oriented travel simulator](image-url)
The simulator’s computer interface was designed following principles of human factor engineering. Fig. 3 gives a screen view of a typical computer interface which provides the virtual driving environment. The interface includes five main parts: (1) basic journey information; (2) traffic condition; (3) GRIP information; (4) vehicle location; (5) other visual and auditory cues. It is driven by the main program modules shown in Fig. 2. The following gives details on the main program modules.

2.2. Main Program Modules

2.2.1 Freeway Network Simulator Module (M0).

This module is the kernel one among all the program modules. It is developed using the extended METANET simulation model. The extended METANET simulation model mainly consists of three components: the link model, the node model and the queue model.

The time and space arguments are discretized. The discrete time step is denoted by \( T \) and \( k \) is the discrete time index, \( k=0, 1, \ldots, K \), where \( K \) is the time horizon considered. A freeway link \( m \) is divided into \( N_m \) segments with segment length \( \Delta_m \) and lane number \( \lambda_m \). The traffic states for segment \( i \) of link \( m \) at time \( k \) are depicted by density \( \rho_{m,i}(k) \) (veh/km/lane), mean speed \( v_{m,i}(k) \) (km/h), and volume \( q_{m,i}(k) \) (veh/h).

[A] Link Model

\[
\rho_{m,i,j}(k+1) = \rho_{m,i,j}(k) + (\frac{T}{\lambda_m \Delta_m})[\gamma_{m,i-1,j}(k)q_{m,i-1}(k) - \gamma_{m,i,j}(k)q_{m,i}(k)]
\]

(1)

\[
q_{m,i}(k) = \rho_{m,i}(k)v_{m,i}(k)\lambda_m
\]

(2)

\[
v_{m,i}(k+1) = v_{m,i}(k) + \frac{T}{\tau} \{v_E[\rho_{m,i}(k)] - v_{m,i}(k)\} + \frac{T}{\Delta_m} \cdot v_{m,i}(k) \cdot [v_{m,i-1}(k) - v_{m,i}(k)]
\]

\[
- \frac{v \cdot T}{\tau \cdot \Delta_m} \cdot \frac{\rho_{m,i+1}(k) - \rho_{m,i}(k)}{\rho_{m,i}(k) + \kappa}
\]

(3)
\[ V_E[p_{m,j}(k)] = v_{f,m} \exp\left( -\frac{1}{a_m} \left( \frac{\rho_{m,j}(k)}{\rho_{cr,m}} \right)^\tau \right) \] (4)

where \( \rho_{m,j} \) is called partial density which represents the portion of \( \rho_{m,j} \) heading for destination \( j \); \( \gamma_{m,j}(k) = \rho_{m,j}(k)/\rho_{m,j}(k) \) is composition rate; \( v_{f,m} \) and \( \rho_{cr,m} \) are free flow speed and critical density, respectively, of link \( m \), while \( a_m \) is another model parameter for link \( m \); \( \tau, \nu, \) and \( \kappa \) are model parameters; \( v_{f,m}, \rho_{cr,m}, \tau, \nu, \) and \( \kappa \) can be validated by real-life traffic data. Equation 1 expresses the conservation of vehicles in a segment. Equation 2 expresses volume in terms of density and speed. Equation 3 expresses a dynamic speed-density relationship which is a validated second-order continuum model. Equation 4 is an empirical function expressing the static speed-density relationship for equilibrium traffic, and is used by Equation 3.

In the original METANET model, mean speed of the freeway segments upstream and downstream of an incident (e.g. accident, roadwork and breakdown) segment calculated by Equation 3 may take unrealistic values. Thus, we make some adjustments of the METANET model to model freeway traffic flow more realistically. In case of an incident occurring in segment \( i \) of link \( m \) and blocks \( b \) lanes, an additional term is added to Equation 3 while calculating \( v_{m,i-1}(k) \) for segment \( i-1 \) (i.e. the segment immediately upstream of the incident)

\[
\frac{\phi_b T [\lambda_{m,i-1}(k) - (\lambda_{m,i-1} - b)] \rho_{m,i-1}(k)}{\lambda_{m,i-1}} \nu^2 \rho_{m,i-1}(k) \]

where \( \phi_b \) is a parameter indicating the influence of incident which can be calibrated in real world. Moreover, the third term of the right hand side of Equation 3 is omitted while calculating \( v_{m,i+1}(k) \) for segment \( i+1 \) (i.e. the segment immediately downstream of the incident). These adjustments in case of incident are inspired by Sanwal et al. (1996) and make the simulation model more realistic.

[B] Node Model

\[ Q_{n,j}(k) = \sum_{\mu \in I_n} q_{\mu,N_n}(k) \gamma_{\mu,N_n,j}(k) \quad \forall (n,j) \] (5)

\[ q_{m,0}(k) = \sum_{j \in I_n} \beta_{n,j}^m(k) Q_{n,j}(k) \quad \forall m \in O_n \] (6)

\[ \gamma_{m,0,j}(k) = \beta_{n,j}^m Q_{n,j}(k)/q_{m,0}(k) \quad \forall m \in O_n, \forall j \in J_m \] (7)

where \( I_n \) is the set of in-flowing links of node \( n \) and \( O_n \) is the set of out-flowing links of node \( n \). \( Q_{n,j}(k) \) is total traffic volume entering node \( n \) at time \( k \) that is destined to \( j \). \( J_m \) is the set of destinations reachable via link \( m \). \( q_{m,0}(k) \) and \( \gamma_{m,0,j}(k) \) are needed in Equation 1 for \( i=1 \).

In Equation 3, \( \rho_{m,N_n+1}(k) \) is needed to calculate \( v_{m,N_n}(k+1) \), and \( v_{m,0}(k) \) is needed to calculate \( v_{m,1}(k+1) \). Empirical equations for calculation of \( v_{m,0}(k) \) (in case that node \( n \) has more than one in-flowing
links) and \( \rho_{m,N_m}(k) \) (in case that node \( n \) has more than one out-flowing links) follow.

\[
v_{m,0}(k) = \frac{\sum_{m \in I_n} v_{m,N_m}(k)q_{m,N_m}(k)}{\sum_{m \in I_n} q_{m,N_m}(k)}
\]

\[
\rho_{m,N_m+1}(k) = \frac{\sum_{m \in O_n} \rho_{m,1}(k)^2}{\sum_{m \in O_n} q_{m,N_m}(k)}
\]

When there is no route guidance at bifurcation node \( n \), \( \beta_{n,j}^m \) take the value of \( \beta_{n,j}^N \) which is the nominal splitting rate in absence of guidance and is a known constant.

When there is route guidance (e.g. route recommendation) at bifurcation node \( n \) which provides a direction (i.e. an out-flowing link) towards a certain destination \( j \), \( \beta_{n,j}^m \) is a control variable.

[C] Queue Model for Origins

The queuing behavior at origin \( O \) is described as follows.

\[
w_{o,j}(k+1) = w_{o,j}(k) + T[\theta_{o,j}(k)d_{o}(k) - \gamma_{o,j}(k)q_{o}(k)]
\]

\[
q_o(k) = \min\{d_o(k) + w_o(k)/T, Q_o \min\{1, (\rho_{\text{max}} - \rho_{\mu,1})/(\rho_{\text{max}} - \rho_{\mu,cr})\}\}
\]

where \( w_o(k) \) is the number of queuing vehicles of origin \( O \) at time \( k \), \( w_{o,j}(k) \) is the portion of \( w_o(k) \) destined to \( j \), \( d_o(k) \) is the demand of \( O \) at time \( k \), \( \theta_{o,j}(k) \) is the portion of \( d_o(k) \) destined to \( j \), \( q_o(k) \) is the flow that enters the network via origin \( O \) at time \( k \), \( \gamma_{o,j}(k) \) is the portion of \( q_o(k) \) destined to \( j \), \( \rho_{\text{max}} \) is the maximum density, \( Q_o \) is the capacity of origin \( O \), \( \mu \) in \( \rho_{\mu,1} \) and \( \rho_{\mu,cr} \) represents the immediately downstream link of origin \( O \).

In summary, given all the inputs needed for simulation that include \( d_o \), \( \theta_{o,j} \), and \( \beta_{n,j}^m \) at all time periods \( k=0,1,..,K \), and the initial process states ( \( \rho_{m,i,j}(0), v_{m,j}(0), \) and \( w_{o,j}(0) \)), the simulation model automatically outputs \( \rho_{m,1}(k), v_{m,j}(k), \) and \( q_{m,j}(k) \) of all segments and \( w_o(k) \) for all origins in the network. Other variables and measures of interest (e.g. route travel time) can be derived using these fundamental simulation outputs.

2.2.2 Basic journey information generating module (M1).

This module, combined with the METANET simulation module (M0), generates the basic journey information including current time, departure time, elapsed time and elapsed travel distance (Fig. 3). Current time in the hypothetical journey progresses at a user-specified rate which is faster than in real world. The rate should not be too high; otherwise unrealistic feelings of the journey by subjects will be caused. Departure time is pre-specified by the simulator. Elapsed time updates in accordance with current time. Given segment speeds for all time steps, the simulator use an algorithm (Gan, 2010) to push the vehicle forward along the subject-selected route. Thus the distance traveled by the vehicle since setting off is automatically updated when time progresses.
2.2.3 Traffic condition generating module (M2).

The road scene has a 3-dimention visual effect. Different traffic conditions (heavy, medium, and light traffic) are indicated by the spacing and concentration of vehicle in the road scene. Traffic condition is determined by a specific algorithm based on METANET simulation results.

2.2.4 GRIP information generating module (M3).

In the simulation, a GRIP information generating algorithm reflecting the reactive GRIP information provision strategy in Shanghai is used. The logic of the GRIP information provision strategy follows. First, traffic detectors (e.g. loop detectors) collect traffic data. Then, the collected traffic data are processed to derive mean speeds for each “information oriented section”. Here an information oriented section is the smallest pixel of the LOS map displayed on a GRIP panel that a traveler can perceive. Last, the mean speed of an information oriented section is mapped to a specific color-coded LOS according to a validated empirical speed-LOS relation. The LOS information is updated at each updating interval. A typical speed-LOS relation in Shanghai expressway management are: (a) If speed is not higher than 20 km/h, LOS is ‘heavily congested’ and is coded ‘red’. (b) If speed is between 20 km/h and 40 km/h, LOS is ‘medium congestion’ and is coded ‘yellow’. (c) If speed is higher than 40 km/h, LOS is ‘normal’ and is coded ‘green’. The speed thresholds for LOS judgment are usually application specific. In the simulation framework, speed of an information oriented section is derived from of segment speeds.

2.2.5 Vehicle location tracing module (M4).

The road network plan is used to give the subject a spatial cognition and feeling about his/her current location in the network. The icon representing the subject’s vehicle continuously moves forward. Upon approaching the downstream detour point, a schematic intersection plan appears on the upper-left of the screen which indicates the link that the vehicle is travelling on and the downstream links which the subject can choose. If there is a GRIP upstream the detour point, the GRIP information is also displayed. The permitted time for a subject to read the schematic intersection plan and GRIP information is about 5 seconds. The subject is required to choose a downstream link (with mouse click). If the permitted reading time passes and a subject has not yet responded, the subject’s vehicle will be assigned to the straightforward downstream link, i.e. no turn occurs at the detour point.

2.2.6 Other visual and auditory cues module (M5).

Other visual and auditory cues which are developed to enhance the realism of the simulator include the speedometer reading, the pitch of an audible engine sound, etc. The speed displayed by the speedometer is derived from segment speeds calculated by METANET.

2.3 Experimental Procedure

In our current work we have divided each simulator experiment session into 5 phases:

Phase 1: Introduction
- Questions on personal characteristics.
- Explanation on GRIP.
- Explanation of how to use the simulator.

Phase 2: Familiarization
- One journey without GRIP designed to familiarize the subject with the simulator and the network.
Phase 3: Reaction to GRIP
- Introduction to concept of GRIP guidance.
- Several journeys with GRIP in the network introduced in the above phase.

Phase 4: A sequence of stated preference questions
Phase 5: Direct questions on the perceived usefulness of GRIP guidance and the user’s normal route choice criterion.

2.4. Simulator Output

The data collected by the simulator includes 3 parts: (a) Driver characteristics including gender, age, level of education, years of driving experience, frequency of using expressway, and driver type, etc. (b) Route choice decisions including pre-trip route choice and en-trip route choice. (c) Answers to attitudinal questions.

3. A prototype simulator

The author used ASP (Microsoft active server pages), Adobe Flash CS 4 and Microsoft Access to develop a prototype of the GRIP-oriented travel simulator. The hypothetical journey is a commuting trip in a road network (Fig. 4a) which is extracted from a simplified part of the urban expressway network in Shanghai. Fig. 3 depicts a typical screen taken from travel simulator. Fig. 4b shows a prompting menu requiring the subject to choose a downstream link.

The travel simulator has been used to collect behaviour data on driver response to different types of VMS messages such as GRIP information, text VMS information and hybrid information (graph + text) and econometric models were developed using these data (Gan and Wang, 2011).

4. Concluding Remarks

This paper proposed a travel simulator for collecting behavioral data on driver response to GRIP. The simulator is dedicated to collecting data on GRIP response in the literature. Benefiting from recent advancement of traffic flow theories, the traffic network conditions and GRIP information are driven by the extended version of the validated high-order continuum model METANET, thus describing freeway traffic flow more accurately and enhancing the realism of the simulator. The methodology for simulator design and the experimental procedure were presented. A prototype simulator with a small expressway network was developed through a case study.
In future, the simulator will also be improved with great efforts to make its computer interface more user-friendly and enhance the ease of use of it. Also, other travel choice dimensions such as departure time can be considered in the simulator.

With the transportation community’ rapidly increasing interest in deploying GRIP, collecting GRIP related behaviour data has become a crucial issue for systematic and comprehensive model development of driver route choice response to GRIP. The proposed GRIP oriented travel simulator is an initial attempt in developing an effective computer-aided tool for collecting GRIP related behavioral data.

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