Title:

DESIGN AND DEVELOPMENT OF A SIMULATION TOOL TO INVESTIGATE DRIVER BEHAVIOUR WITH RESPECT TO INNOVATIVE TRAVEL INFORMATION

Authors:

**Jingqiu GUO***
PhD candidate
The University of Western Australia
M 261, 35 Stirling Highway, Crawley WA 6009, Australia
Telephone: 0061-08-64887287
jingqiu@biz.uwa.edu.au

**John TAPLIN**
Professor
The University of Western Australia
M 261, 35 Stirling Highway, Crawley WA 6009, Australia
Telephone: 0061-08-64882081
jtaplin@biz.uwa.edu.au

**Min QIU**
Senior lecturer
The University of Western Australia
M 261, 35 Stirling Highway, Crawley WA 6009, Australia
Telephone: 0061-08-64883729
mqiu@biz.uwa.edu.au
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ABSTRACT

It has been widely recognised that providing drivers with In-Vehicle Information Systems (IVIS) may change their behaviour in ways that are beneficial to the performance of the transport system as a whole as well as users’ satisfaction. This paper presents the design and development of an interactive computer simulation tool, through which stated-preference data on driver behaviour to traffic information is collected.

The design is based on a multidimensional decision process, with choices of departure time, car travel route and driving style, specifically with instantaneous cost information under different driving speeds, brake and acceleration modes, and tyre pressure conditions. Respondents are to be presented with several hypothetical scenarios in order to generate orthogonal profiles with respect to traffic information, including travel purposes, information media, sources and magnitudes of delay, information strategies and choice suggestions. On the one hand it simulates the situations of real-time information provided to respondents, and on the other hand collects data on the effects of such information on respondent behaviour in relation to departure time, route and driving style.

It is concluded that in order to enhance the understanding of the behaviour change of drivers in response to innovative in-vehicle information, a stated-preference survey based on a computer-based simulator can generate scenarios that more closely mimic what travellers would experience. The nature of such a tool helps in capturing those subtleties of information provided, which would otherwise be hardly obtained through other survey methods such as mail-out questionnaires and telephone interviews. This will help system designers and policy-makers in preparing for the technological revolution, and support their decision-making.

KEYWORDS

In-Vehicle Information Systems (IVIS), Multidimensional decision process, Computer assisted personal interviews, Discrete choice model.
1. INTRODUCTION

Recent developments in computer science and wireless communication technologies present a wide vision among telecommunication operators, transport agencies, academia, as well as policy makers of a revolution in Advanced Traveller Information Systems (ATIS), which is called next generation ATIS (Kenyon and Lyons, 2003; Chorus et al., 2006). Currently these ATISs are still in the initial stage. However, to provide drivers with dynamic, real time and personalised travel information has the potential of influencing user choices for departure times, routes, and even driving styles.

Stated Preference (SP) surveys have been widely used to collect information to establish models to investigate users transport choice behaviour. In the content of ATIS, in addition to the number of variables and levels for variables to be considered in designing the platform of collecting data, graphic images that simulate real-time information are essential for presenting information in individual scenarios. This requirement makes other methods such as mail-out and telephone surveys infeasible, and a computer-based simulation tool is chosen to carry out the data collection, which can be run through the Internet and/or as part of computer assisted personal interviews (CAPI).

This paper reports the design and development of a computer-based simulator that is used to investigate how drivers respond to innovative in-vehicle information when they are driving a vehicle with an eco-driving support device, a version of the IVIS. The stated-preference information collected through the simulator can be used to estimate a corresponding choice model. The simulator graphically mimics a situation when the driver is travelling on an urban road connecting travel origin and destination and is prompted by the information system to take an action in relation to change departure time, driving route and driving style.

The remainder of this paper is organised as follows. The next section presents a theoretical framework on the multidimensional choice model and a mixed multinomial logit (MNL) model specification. Section Three presents the design and development of the simulation tool. The last section summarises this paper, and indicates future work.
2. METHODOLOGY

2.1 A theoretical model

An integrative analytical model, as shown in Figure 1, is proposed for studying the use and effects of the next generation ATIS.

The right side of Figure 1 shows that the advanced traffic information services are evolutionary and based on iterations of analysis, development, as well as implementation. It indicates two overall approaches to new ATIS services design for emerging technologies: user-centred design and technology-centred design. In the user-centred approach, design moves from understanding of current practice to hypothetical future use. In the technology-centred approach, usability evaluation is employed to examine the impact on current practice. Usually the trend in information and communications technology (ICT) is driven by technology, rather than user-centred approaches. According to the research model, the two approaches will be combined for the next generation of advanced traffic information design. The ability to create smaller devices with increased computing power directly promotes the development of new mobile devices, and the end of the increased availability is a day when mobile devices will be able to connect to high-speed and newer broadband networks anytime anywhere. Integrative research between the user-centred and technology-centred approaches is pushing the boundaries of wireless technology in transport systems.

On the left side of Figure 1, the model represents user choices for information acquisition and the effect on their travel choices under conditions of traffic information and knowledge limitations. When a traveller decides to acquire information, his/her travel choices may be changed in terms of known alternatives and uncertainty. With updated perceptions, a traveller again faces a sequential travel choice, and the full sequence of decisions can be observed as an iteration process.
2.2 Multidimensional Choice Model

For the purpose of this study, discrete choice modelling is used to model driver responses to traffic information. Discrete choice models assume that the probability of an individual choosing a given option from a set of alternatives is a function of the context variables and the relative attractiveness of the option (Louviere, 2000).

In most discrete choice studies, the choice set has been relatively simple. However there are some situations where the members of alternatives are combinations of multiple choice dimensions. This research is based on a three-level dimensional choice decision process, with choices of departure time, car travel route and driving style, where the multidimensional structure of the choice set leads to the elements in choice set sharing unobserved as well as observed attributes (see Figure 2).

![Travel decision tree with the provision of information](attachment:image.png)

Figure 2: Travel decision tree with the provision of information

Basically the nested logit model can be used to model any case where subsets of the feasible alternatives share unobserved components of utility (Ben-Akiva and Lerman, 1985). For the nested logit model to be used, a set of reasonable assumptions are made as following: All disturbance terms are mutually independent; all components of the total disturbance involve level 1, but not all the higher levels have zero variance; The sum of the disturbance terms at level 1 and those at the next lower level 1-l are identically Gumbel Distributed (Ben-Akiva and Lerman, 1985).
According to the decision tree, the model specification is specified as a standard linear-in-the parameters function. The utilities of the standard MNL model specific to individual $n$, $n = 1, \ldots, N$ are:

No change
\[ U_{nc,n} = X_{nc,n} \beta + \gamma_{nc,n} \]  
(1)

Change departure time
\[ U_{ct,n} = \alpha_{ct,n} + X_{ct,n} \beta + \gamma_{ct,n} \]  
(2)

Change route
\[ U_{cr,n} = \alpha_{cr,n} + X_{cr,n} \beta + \gamma_{cr,n} \]  
(3)

Change driving pattern
\[ U_{cd,n} = \alpha_{cd,n} + X_{cd,n} \beta + \gamma_{cd,n} \]  
(4)

Change route and driving pattern
\[ U_{crd,n} = \alpha_{crd,n} + X_{crd,n} \beta + \gamma_{crd,n} \]  
(5)

Mixed logit is a highly flexible model that can approximate any random utility model (McFadden and Train, 2000). It obviates the three limitations of standard logit by allowing for random taste variation, unrestricted substitution patterns, and correlation in unobserved factors over time (Train, 2003). The specification of a random coefficient mixed logit model uses the following utility specification (for a decision maker $n$ choosing alternative $i$ from a choice set of $i$ alternatives):

\[ U_{in} = X_{in} \beta + \sigma_i \varepsilon_{in} + \gamma_{in} \]  
(6)

where $X_{in}$ are observed variables that relate to the alternative, $i$, and decision maker, $n$; $\beta$ is a vector of coefficients of these variables; $\gamma_{in}$ is a zero-mean, random term that is iid extreme value; and $\varepsilon_{in}$ is a Gaussian, zero-mean error term with a standard deviation $\sigma_i$. 

Figure 3: The nested logit model for a three-level choice set
Under the mixed logit structure, the utilities specific to individual \( n, n = 1, \ldots, N \) are:

\[
U_{nc,n} = X_{nc,n} \beta + \sigma_{nc} \varepsilon_{nc,n} + \gamma_{nc,n} \\
U_{ct,n} = a_{ct} + X_{ct,n} \beta + \sigma_{ct} \varepsilon_{ct,n} + \gamma_{ct,n} \\
U_{cr,n} = a_{cr} + X_{cr,n} \beta + \sigma_{cr} \varepsilon_{cr,n} + \gamma_{cr,n} \\
U_{cd,n} = a_{cd} + X_{cd,n} \beta + \sigma_{cd} \varepsilon_{cd,n} + \gamma_{cd,n} \\
U_{crd,n} = a_{crd} + X_{crd,n} \beta + \sigma_{crd} \varepsilon_{crd,n} + \gamma_{crd,n}
\]  

(7)  
(8)  
(9)  
(10)  
(11)

2.3 Travel choice based on vehicle’s operating efficiency

It has been widely recognised that on urban roads some drivers tend to choose faster-time routes that may not be the best from the perspective of the vehicle operating efficiency. This phenomenon can probably be explained by lack of real-time information on choice alternatives that are beneficial to the operating efficiency of vehicles. Figure 4 shows a three layer decision model which is based on vehicle operation efficiency.

![Three-layer choice model based on vehicle’s operation efficiency](image)

Currently most navigation systems optimise route by the shortest time or distance instead of the lowest fuel consumption. One exception is the research by Ericsson et al. (2006) which presents a prototype driver support tool which optimises route choice for the lowest fuel consumption. To better understand the effects on fuel consumption of driving in different congested situations, a field trial was carried out to compare the fuel consumption of travelling in peak-hour traffic to normal daytime running conditions in October 2008 in Perth. As shown in Table 1, fuel consumption on a congested road is 10.9 L/100km, but only 8.0 L/100km in daytime running. In other words, it costs about AUS $5.09/100km in congested conditions more than in normal conditions (assuming diesel price is AUS $1.75 /litre). In view of the significant financial costs associated with
Among many factors, the tyre pressure of a vehicle contributes considerably to vehicle operating efficiency as well as to its safety on roads. Some studies show that 40% of vehicles have one or more tyres under inflated, and a 25% decrease in tyre pressure can cost 5-10% more on fuel and 25% on tyre life (GCC, 2007). Research by the US National Highway Traffic Safety Administration suggests that 1.4% of all accidents resulting in 10,000 road deaths in the US could be prevented each year by monitoring tyre pressure. Conclusively using radial tyres can contribute to less fuel economy, longer tyre life and greater riding safety.

However, it appears that this factor has not drawn due attention of drivers and that tyre pressure maintenance has remained a low priority. According to the data collected from a short questionnaire on UWA campus and at a transport forum in Perth, more than 85% of respondents who have a car, check the tyre pressure less than once a month. To a large extent, this situation has been due to lack of prompt information, with the tyre pressure of a passenger vehicle becoming known only when the driver occasionally pumps tyres at a petrol station. It is likely that even when pressure is checked, the driver does not necessarily know the magnitude by which the tyre pressure impacts on the vehicle’s operating efficiency.

With the development of innovative sensing technologies, it becomes possible to provide to drivers with real time tyre pressure data with a Tyre Pressure Monitoring System (TPMS). TPMS is designed to measure and display tyre operation, and alert the driver instantly of any tyre pressure irregularities.
3. Experimental design and development

Computer Assisted Personal Interviewing (CAPI) is a computer assisted data collection method for replacing paper-and-pen methods of survey data collection. CAPI has been regarded as the current state-of-the-art in stated preference surveys. The subjects are to be presented with various travel hypothetical scenarios, in order to generate the complete travel profile with traffic information. It is specified as an information service that takes into account user personal preferences concerning route, departure time and driving style. The use of a simulated environment developed for this survey can enable the feature of generating dynamic SP scenarios. From a statistical perspective, more variability presented to the respondent is an advantage. In other forms of survey design, such as paper-and-pencil surveys, the same limited set of options is generally presented to all respondents as it may be too costly to prepare a separate design for each respondent.

This section discusses separately the conceptual and computational elements used to build up the simulation tool.

3.1 Software Platforms

The Server Operating System:
Windows Server 2003 is used as the server operating system, which takes the best of Windows 2000 Server technology and makes it easier to deploy, manage, and use. As a multi-purpose operating system capable of handling a diverse set of server roles, Windows Server 2003 includes all the functionality users need from a Windows Server operating system to do more with less, such as security, reliability, availability, and scalability. Meanwhile, it has been extended to incorporate the benefits of .NET for connecting information, user, systems, and so on.

The Programming Language:
This simulation tool was programmed using ASP.net, a unified web platform which is built on the .NET framework by Microsoft. Compared with standard software for a CAPI survey, ASP.net has more power to randomly generate various hypothetical scenarios. C# was used to code the applications that benefit from the common language runtime (CLR), inheritance, as well as type safety. Both the application interface (front-end) and the back-end management interface are developed by ASP.net page and controls framework that can dynamically produce and render web pages.

The Database Server:
Network data and participant results are collected and managed by a Microsoft SQL Server (version 2000) database. Since the survey involves the presentation of large amounts of image data, meanwhile any user can participate in the web-based survey with access to the Internet, the simulator has been tested to work with a satisfied accessing speed under Browser/ Server environment.
**.NET Three Layers Architecture:**
The simulator is based on three layer architecture:

- **Presentation Layer:** provides the application's user interface (UI). Typically, this involves the use of Windows Forms for smart client interaction, and ASP.net technologies for browser-based interaction.

- **Business Logic Layer:** implements the business functionality of the application. The domain layer is typically composed of a number of components implemented using one or more .NET. These components can be augmented with .NET Enterprise Services for scalable distributed component solutions.

- **Data Layer:** provides access to external systems such as databases.

This pattern is able to accrue most of the benefits of the Layered Application pattern while minimizing the negative effects of having to cross too many layers (Fowler, 2003).

### 3.2 Experimental Design
After having identified the alternatives, attributes, the number of attribute levels, and the attribute level labels, it is needed to consider building a statically efficient fractional factorial design. To generate orthogonal designs, in which the columns of the design display zero correlations, Design-Expert 7.0 software was used. Table 2 shows a data table for driving style change choice as an example.

**Table 2: A data table for driving style change choice**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Possible values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expression</td>
<td>In-vehicle information expression strategies</td>
<td>0 'Show cost in Dollar'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 'Show cost in Litre'</td>
</tr>
<tr>
<td>Saving</td>
<td>Cost saving if change driving style</td>
<td>0 '5%'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 '10%'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 '15%'</td>
</tr>
<tr>
<td>Delay_t</td>
<td>Delay time for inflating tyres at a petrol station en-route</td>
<td>0 '5 mins'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 '15 mins'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 '25 mins'</td>
</tr>
<tr>
<td>Fuel_level</td>
<td>Fuel tank level</td>
<td>0 'Nearly full'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 'Half'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 'Nearly empty'</td>
</tr>
<tr>
<td>Suggestion</td>
<td>Information strategies</td>
<td>0 'Provision of no advice'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 'Provision of advice'</td>
</tr>
<tr>
<td>Trip_p</td>
<td>Trip purpose</td>
<td>0 'non-business'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 'business'</td>
</tr>
</tbody>
</table>
3.3 Experimental Development

3.3.1 Introduction section
The home page as shown in Figure 5 has a brief summary of the purpose of the study, procedures, confidentiality, and human research ethics information. A click button captioned ‘Click after reading the above screen carefully’ at the bottom of this page link the subject to the next page. To promise subjects read the introduction carefully, 5-second is set as the shortest browsing time before the button can be activated.

![Simulation on User Response to New Generation ATIS](image)

Figure 5: Homepage screen

3.3.2 Travel network section
A simulated trip from Scarborough Beach Road (Main Street) to the new Business School Building of UWA is examined for the collection of traveller behaviour data. Although there are many potential routes between these two locations, the shortest driving time route (via Mitchell Freeway) is chosen as the normal route. A Google map illustrates the resulting network consists of the origin node is indicated as A, while the destination node is marked as B as shown in Figure 6.
3.3.3 Simulation section
It simulates a package of three sequential travelling choices via an easy-user interface. Each stage has several scenarios, in which the respondent is required to make decisions whether to change the departure time, route and driving style in the existence of pre-trip and en-route travel information.

Departure time change
Pre-trip information is presented inside the simulation with different combinations of attributes include information media, sources of delays, expected delay time, information strategies, and trip purpose. With the back-end management system as shown in Figure 8, widely used for scalable e-business websites, it is much more convenient to manage the front-end factors. There are three decision choices for the respondents: 1) advance the trip to an early time; 2) don’t change departure time; 3) delay the trip to a later time.

Figure 6: A map of the travel network
Figure 7: Application interface screen – Departure time change

Figure 8: Back-end management screen – Departure time change
Route change
While en-route, respondents will receive updated information about their current trip. The information consists of the sources of delays, expected delay time, and information strategies. Meanwhile the locations of information provision, travel time, the alternative route are provided by graphic user interface (GUI), as shown in Figure 9. Different options are available for respondents. They can divert to the alternative routes, make no change, or select not sure. According to the choice made by the respondent, the simulator generates dynamically various following scenarios.

Tyre Pressure
This section is designed to investigate how drivers respond to real-time vehicle tyre pressure information when they are driving with an eco-driving support device. The simulator graphically mimics several scenarios when the drivers is travelling between origin and destination and is prompted by the eco-driving system to take an action in relation to pump tyres to a desired pressure level at a petrol station along the route. The choice set has two alternatives: 1) not pumping tyres during the course of the current trip, and 2) pulling out at a petrol station to pump tyres during the course of the current trip.

Due to time limitation, so far the instrument has only been developed to investigate drivers respond to vehicle tyre pressure information instead of various factors in relative to vehicle operating efficiency, such as speed, braking and acceleration. It is expected to be supplemented into the simulation soon.
The work described in this paper is part of my PhD research. The objective is to study the behavioural responses of travellers under innovative travel information.

To achieve this, a stated-preference survey needs to be conducted in Perth after the instrument is designed. In the recruitment process, social characteristics need to be considered, and the sampling will try to achieve a high level of heterogeneity. However due to the limitations, some potential sample biases can be expected. For example, as a computer based experiment, it is reasonable to expect that the sample will contain a higher fraction of computer literates than in the whole population of Perth. Some previous studies (e.g. Chorus et al. 2007) mentioned that this is likely to imply a lower representation of elderly, and, to some extent, women. Furthermore, people who are interested in travel information services and advanced electronic devices are likely to be over represented with the chosen sampling method.

After survey data is collected, the model estimation will determine the values of parameters. According to the time plan, the whole task will be finished in June 2010.
REFERENCES


