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**The Royal Institute of Navigation  
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## **Using Travel Simulation to Investigate Driver Response to In-Vehicle Route Guidance Systems**

**By**

**Dr Paul E. Firmin** – Institute for Transport Studies, 34-40 University Road, University of  
Leeds, West Yorkshire, LS2 9JT. [Email: pfirm@its.leeds.ac.uk]

**&**

**Mr. Himanshu Budhiraja** – Atkins, Axis, 5<sup>th</sup> East, 10 Holliday Street, Birmingham, B1 1TF.  
[Email: Himanshu.Budhiraja@atkinsglobal.com]

### **ABSTRACT**

A major application for developed satellite navigation systems is the in-vehicle route guidance market. As systems become cheaper to purchase and easier to install and indeed car manufacturers begin to fit the equipment as standard in new vehicles, the potential market for such systems in the developed world is massive. But what are the consequences of giving navigational assistance to car drivers? How will drivers respond to this information? Such information is liable to have a big impact upon driver route choice behaviour and is also subject to their interpretation of the guidance and action upon receiving it. This response may change under different travel circumstances. The impact of collective response to driver guidance is also of importance to traffic engineers and city planners, since routing through environmentally sensitive areas or heavily congested corridors should be avoided. The overall network effects are therefore of key importance to ensure efficient routing and minimal disruption to the road network.

It is quite difficult to observe real-life behaviour on a consistent basis, since there are so many confounding variables in the real-world, traffic is never the same two days running, let alone hour by hour and a rigorous experimental environment is required, since control of experimental conditions is paramount to being able to confidently predict driver behaviour in response to navigational aids. Also the take up of guidance systems is still in its infancy, so far available only to a niche market of specialist professionals and those with disposable income. A need to test the common public's response to route guidance systems is therefore required.

The development of travel simulation techniques, using portable computers and specialist software, gives robust experimental advantages. Although not totally realistic of the driving task, these techniques are sufficient in their realism of the decision element of route selection, enough to conduct experimental studies into drivers' route choice behaviour under conditions of receiving simulated guidance advice. In this manner driver response to in-vehicle route guidance systems can be tested under a range of hypothetical journey making travel scenarios.

This paper will outline the development of travel simulation techniques as a tool for in-vehicle route guidance research, including different methods and key simulation design requirements. The second half of the paper will report in detail on the findings from a recently conducted experiment investigating drivers' response to route guidance when in familiar and unfamiliar

road networks. The results will indicate the importance of providing meaningful information to drivers under these two real-life circumstances and report on how demands for route guidance information may vary by type of journey. Findings indicate that the guidance acceptance need not only depend on the optimum route choice criteria, it is also affected by network familiarity, quality and credibility of guidance advice and personal attributes of the drivers.

## **1. INTRODUCTION**

The use of travel simulation techniques to monitor driver response to simulated in-car guidance and information systems first gained popularity in the late 1980's, as personal computer power became affordable and more common place. Transport researchers involved in conducting driver behavioural studies were quick to realise the merits of portable specialist travel simulations as an enhanced form of computer aided personal interview (CAPI), a well known market research technique (Richardson, Ampt & Meyburg, 1995). Hence the development and widespread availability of low cost portable computing power and software during the late 1980's led to the facility and flexibility of being able to conduct detailed choice interviews either in hall, office or home situations and led to the direct development of travel simulation techniques as a pseudo driving environment for capturing traveller decision making behaviour.

This paper will therefore outline the advantages of using travel simulation, will give a brief history to the development of the technique during the past few years and will detail the features of a simulator known as TRAVSIM (Firmin, 1995a), developed at the University of Leeds, UK. The paper will also detail one specific application of the simulator to the study of driver response to simulated in-vehicle route guidance advice under different levels of network knowledge. The paper will conclude with detailed results from the study and will inform upon the success of travel simulation as a research technique for studying driver route choice behaviour and response to new technologies, prior to their implementation.

## **2. ADVANTAGES OF TRAVEL SIMULATION TECHNIQUES**

The major advantages offered by travel simulation techniques are the ability to study complex travel decisions, which would be difficult, if not impossible, to observe in the real world due to a lack of control over experimental conditions. It is not possible, for example to guarantee the same traffic conditions from day to day, due to natural variability. Traditional survey techniques such as stated preference questionnaire surveys, or personal interview methods are not particularly useful for testing response to new technologies, since they lack an element of dynamism that a travel simulation is capable of portraying. For example, in the simulated travel world it is possible to make the subject driver experience the consequences of their previous decisions. As an example, a driver ignoring route guidance advice might subsequently pay the penalty by being made to sit in a queue of traffic, adding to their overall journey time. In this manner simulators are able to provide active feedback to subjects (Firmin, 1997).

Because travel simulators do not require expensive full scale driving simulator levels of fidelity, they can be made relatively cheaply and are also fully portable, being able to be run from any laptop, or desk top computer. This level of portability makes them ideal for collecting data in the hall or office workplace. Hence the ability of mass automatic data collection, relatively quickly

and cheaply compared to the use of full scale driving simulation is also a major advantage. Since the driving task is simplified or even removed and the decision environment is simulated in real-time, travel simulation also offers a safe environment for the study of complex decision making.

Testing of systems prior to full scale implementation is another key advantage and the capability to test combinations of information sources are another experimental bonus. This makes it possible to give conflicting or incorrect guidance information to drivers and study how they react and respond to mis-information. The method becomes particularly powerful when testing conflicting information. For example, what would a driver do if faced with a clear road ahead, but a navigation system informing them to make a right turn off from the major road ahead?

Travel simulation therefore offers a reliable method for capture of driver route choice decision making behaviour, particularly in response to new driver information technologies, such as in-vehicle guidance and traffic congestion warning systems; text based Radio Data Systems (RDS-TMC); or roadside location, direction and variable message sign information.

### **3. A BRIEF HISTORY OF TRAVEL SIMULATORS**

Early examples of travel simulation methods were based on simplistic two-dimensional black and white graphic displays or mock up road-scene views. An early example of which being the Urban Driving Simulator, developed by Leiser & Stern (1988) and used to collect data on driver journey time assessments. Early simulators also relied upon hybrid simulator designs, often involving multiple screens, one for the road view and one to project computer generated navigation advice, such as the Systems Technology Inc. laboratory simulator (Allen, Ziedman, Rosenthal, Stein, Torres & Halati, 1992). This simulator was also one of the first to use realistic photographic images of freeway travel conditions.

The computer based simulation technique gained popularity throughout the 1990's, particularly with Japanese and North American transportation researchers. The computer based laboratory simulation developed by Iida, Akiyama & Uchida (1992) in Japan, made use of a repeated sequence of hypothetical journeys, in order to capture driver predictions of travel times on a simulated daily basis. A simulator developed specifically to study route choice between parallel routes and response to travel advice was developed by Vaughn, Reddy, Abdel-Aty, Kitamura & Jovanis (1995) at Davis, California, USA. Two further sophisticated simulators have been developed in the USA to monitor driver response to advanced traveller information systems. Namely, FASTCARS, developed by Adler & McNally (1994); and a simulator developed at MIT by Koutsopoulos, Lotan & Yang (1994), both of which depicted computerised plan views of road networks along which subjects were exposed to experimenter controlled traffic conditions and simulated guidance technologies. A more recent simulation technique has also been developed and applied by Kantowitz, Hanowski & Kantowitz (1997) at the Battelle Human Factors Transportation Centre, to test response to the reliability of information provision.

The first travel simulator developed by the University of Leeds in the UK was known as IGOR (Interactive Guidance On Routes) and consisted of a simplistic overhead map type display, approximating to a road sign in layout (Bonsall & Parry, 1991). Simulated dynamic route guidance advice was successfully tested with this simulator, but the graphics were not

particularly realistic. This led to the subsequent development of three further simulators; VLADIMIR, TRAVSIM and PARKIT, which all utilised elements of through the windscreen semi-realistic driving views of the road-scene ahead and associated information. The main differences between these three simulators was their portrayal of the network, with TRAVSIM and PARKIT being based on purely hypothetical computer generated travel environments, whilst VLADIMIR was based on computer digitised images of a real network in Leeds (Bonsall, Clarke, Firmin & Palmer, 1994). Differences in the representation of traffic congestion were also used in these simulators, with VLADIMIR and PARKIT using car shaped graphics to represent queuing vehicles. The simulators have all been successfully used to capture driver response to route guidance, VMS, road pricing and parking guidance information systems.

#### 4. THE TRAVSIM SIMULATOR

The TRAVSIM (an acronym of **TRAVel SIMulator**) simulator program code was written and developed by Firmin (1995a) at the University of Leeds, to enable both the testing of driver response to Variable Message Sign information and In-Car Route Guidance advice; whilst simultaneously permitting the testing of various features of the travel simulation technique itself, since this was a relatively new research tool and little was known about it. The simulator could therefore be operated in a variety of modes, with varying amounts of feedback provision.

The simulator is based upon a hypothetical computer generated network. The simulated environment includes a mock dashboard, including: a clock, mileometer, speedometer, compass, and an in-car device onto which is superimposed either text or graphic navigation advice. The windscreen view, includes: local and directional signs – indicating One-way streets and No entry roads, working traffic signals, route hierarchy and traffic conditions depicted by text descriptions. Additionally a rear view mirror indicates impatient traffic approaching from behind! The simulator represents driving time in artificial speeded up time and decision time in real time (seconds). As the subject negotiates a path through the network with the aid of a paper map, the simulator automatically logs their route choice decisions at each junction along the way and records the time taken to decide in real time. This data can be subsequently analysed in respect of the traffic and guidance information conditions. The simulator is capable of multiple journey scenarios between different points in the network, which are set by the experimenter. Each journey is described to the subject driver before undertaking the journey, to give a trip purpose context. The subject is free to choose any route they desire to meet their destination objective and are also free to use navigation advice or not.



**Figure 1: The TRAVSIM\_G junction decision environment screen display**

## 5. ROUTE GUIDANCE EXPERIMENT

A study aimed at understanding the impact of network knowledge on response to driver route guidance systems in terms of the variability in compliance with these systems under different levels of network knowledge was conducted in 2004 using TRAVSIM. It was to establish the circumstances under which such systems would have greater acceptability and hence know the prospective markets for such systems (Budhiraja, 2005). The following sections describe the study, its key findings and its implications for system development and marketing.

### 5.1 Previous Research on Driver Response to Guidance

Research into driver response by Bonsall, Pickup & Stathopoulos (1991), Bonsall & Joint (1991), Adler & McNally (1994) and Lotan (1997) have shown that compliance to navigational systems is a function of:

- i. The type of system, with a clear distinction between variability in compliance to guidance and Information.
- ii. Credibility of the system in terms of the past experience that the drivers' have had with the systems.
- iii. Quality of guidance, which drivers' judge based on the local evidence, and then tend to reject it if it is against the local evidence.
- iv. Familiarity with network. The research shows that the compliance with regard to the guidance is higher in unfamiliar areas as compared to familiar networks (*Refer section 5.2 for details*).
- v. Personal characteristics especially age, gender and driving experience of the drivers impacts drivers' compliance to guidance.

### 5.2 Driver Network Knowledge - Impact on Driver Compliance

Research into driver response to navigational systems has indicated that driver preference of Guidance depends on their network familiarity, besides other independent variables affecting route choice (Bonsall et al, 1991). The study showed that the percentage of respondents preferring guidance over information was 76% in unfamiliar areas, whereas for the familiar areas it was only 13%. Attitudes and experiences of LISB users (an in-car system that provided real time traffic information and guidance to drivers) as analysed by Bonsall et al (1991) showed that around 23% of the total users "*almost always*" followed the guidance on familiar journeys, whereas around 62% of the users "*almost always*" used the guidance when in unfamiliar areas.

Work by Bonsall and Joint (1991) analysing the IGOR (a route choice simulator) results for assessing the driver compliance with route guidance advice show that acceptance of guidance decreases with the increased network familiarity, the rate of decrease being a function of perceived quality of guidance or information. A Study by Adler and McNally (1994) reported that drivers' with higher network familiarity levels had lower tendency to use Highway Advisory Radio (HAR) and In-Vehicle Navigation System (IVNS) as opposed to the ones with lower familiarity. A study to understand this aspect of driver route choice behaviour was hence undertaken. Adler (2001) also found that there may be significant short-term advantages to providing in-vehicle route guidance and navigation information to unfamiliar drivers.

## 6. DETAILED EXPERIMENTAL DESIGN

Various data collection techniques were reviewed and the use of a Travel Simulator was considered most appropriate. Research on route choice travel simulators by Bonsall et al (1994), Koutsopoulos et al (1994), Firmin(1995a & 1995b), Bonsall, Firmin, Anderson, Palmer & Balmforth (1997) and Firmin (1997), have all established the use of travel simulators as efficient, inexpensive, easy to use, reliable and realistic tools to collect data on route choice behaviour under controlled experimental conditions.

### 6.1 Design of Simulator Driving Tasks

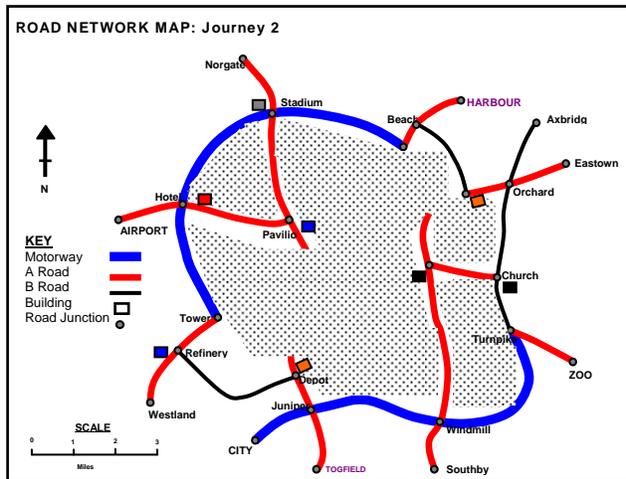
The “subject drivers” were invited to do 5 simulated journeys each (one trail and four experiment journeys), between a specified origin-destination pair on a hypothetical network with gradually increasing network knowledge. For the present study controlling the independent variable ‘*Network Knowledge*, in terms of the familiarity with network layout and the traffic conditions on them was of key importance. This was achieved by gradually increasing the network knowledge by provision of paper maps to “*subject drivers*”, by making them undertake simulated journeys between the same OD pairs over successive runs and through use of landmark buildings and sign posts displayed en-route via the windscreen views. The simulator was designed to present the subject drivers with a semi realistic driving experience through simulated driving features as shown in **Figure 1**.

The experiment kept all other factors affecting route choice like the traffic conditions, time of the journey and journey purpose the same across all scenarios to ensure minimal influence of these factors on drivers’ response. The quality of guidance was optimal for the main journeys (Journeys 2, 3 &4) to ensure that the impact of network knowledge could be studied independent of other influencing factors. However for the last journey (journey 5) it was also intended to study the impact that quality and credibility of such systems, based on drivers’ past experience due to previous optimal journeys, has on drivers’ response by using an additional journey with sub-optimal guidance (Budhiraja, 2003 & 2005).

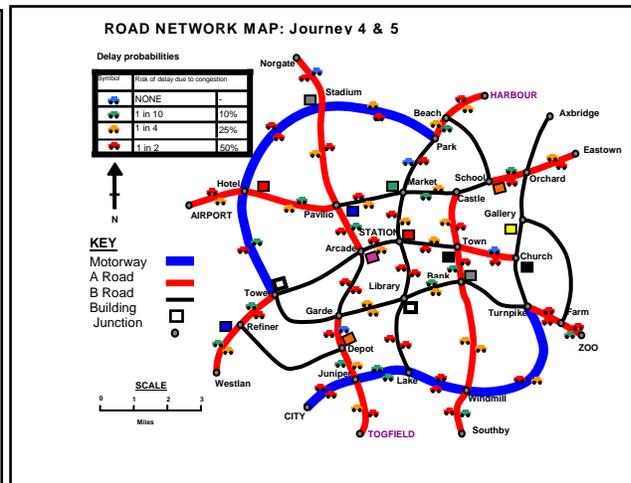
### 6.2 Design of Network Representation and Driver Knowledge

Paper Maps with three levels of network details were designed and provided to the subjects for different journeys to control their network knowledge. They represented:

- i. *Partial Knowledge* (journey 2) showing orbital route and A-road radials only (**Figure 2**);
- ii. *Good Knowledge* (journey 3 )with complete network layout showing connectivity; and
- iii. *Complete Knowledge* (journeys 4&5) about network layout and travel conditions represented by different coloured cars showing the delay probabilities on some important links like the city centre links, motorways and the A-roads (**Figure 3**). The delay probabilities were made to coincide with the actual travel conditions being used by the simulator to ensure that the traffic conditions visible to the subject driver while driving were in line with the delay probabilities shown on the map.



**Figure 2: Map showing Partial Network Knowledge**



**Figure 3: Map showing Complete Network Knowledge**

## 7. DATA COLLECTION PROCEDURE

### 7.1 Subject Recruitment

Subjects were recruited on a random sampling basis from the staff and students of the University of Leeds, through a three day telephonic recruitment procedure. With the prerequisite being that the subject was a driver with a valid driving license, it was ensured that an almost equal proportion of males and females in all age groups were recruited for the experiment. A well structured recruitment telephonic conversation was used to recruit willing subjects for the experiment. The surveys were conducted in July 2004. The distribution of route attributes like travel time, travel distribution was not known, so it was considered appropriate to target a sample size of 30 subjects for the experiment, which is suggested to be statistically significant because for large values of sample size ( $N \geq 30$ ) an arbitrary distribution or a distribution with unknown population variance like t-distribution, also approaches to normal and if need be, normal distribution tests can be applied to the data set.

### 7.2 Interactive Interview Procedure

The interview was conducted in a pre-decided, well structured format rehearsed well before the onset of surveys to ensure that there were no biases in the experiment due to conduct of the survey. The drivers were explained annotated screen shots of the simulator display before the start of the simulated journeys. The level of paper map that was available was also explained to the subject before the start of each journey. Interviews were carried out in an unobtrusive manner. The subject's seriousness about the experiment and their comfort level with regard to the use of the simulator and the map was also noted. The session normally took around 45minutes to a maximum of an hour.

## 8. KEY STUDY FINDINGS

### 8.1 Sample Characteristics and Opinion:

The subjects were between 20 to 65 years with a third of the sample being females. The subjects were experienced drivers with around 90% having been driving for over 5 years. Subjects' top three route choice criteria that they used in real life while making a car journey in general, as stated by them, was weighted and the results show that "minimum journey time" was the most important (33.6%) followed by "avoidance of congestion" (18.6%) and then the "most familiar route" (14.2%) (Figure 4).

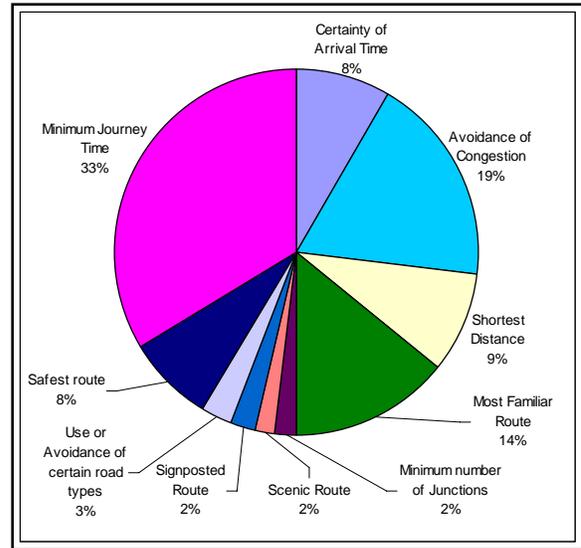


Figure 4: Stated Route Choice Criteria

### 8.2 Journey Performance

Minimum journey time being the most important route choice criteria for a third of the sample was used as the route choice attribute to analyse journey performance. Difference in journey performance, if any, for different journeys would indicate different levels of network knowledge as one of the causal factors impacting drivers' route choice because the only changing variable between journeys 2, 3 and 4 was the level of network knowledge. Whereas the differences in journey performance, if any, between journey 4 and 5 would indicate the impact of quality of guidance (the changing variable) on drivers' response to route guidance

Journey pairs were analysed for differences in journey performance using the Wilcoxon test, which analyses the differences between 2 related samples, to understand the level of network knowledge at which drivers' compliance to guidance becomes significantly different. Table 1 shows significant differences between journey performance for journeys 2, 3 and 4 indicating, that all other factors being same, journey performance varies with different levels of network knowledge.

Significant difference between journey performance for journey 4 and 5, (good quality guidance versus sub-optimal guidance or information) shows that even with sub-optimal guidance, drivers, under certain circumstances like good past experience, trust in the system and such like reasons, might still comply with the sub-optimal guidance. This could be because of the assured certainty of being able to reach their destination by following the turn by turn advice given by such systems.

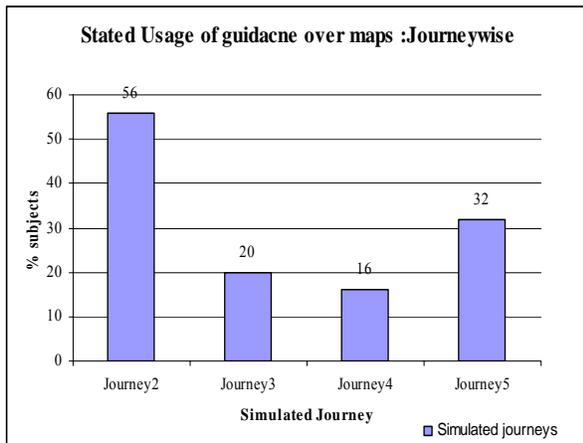
Table 1: Wilcoxon test statistics for differences in driving times for subjects'

Variable: Driving time between journeys	Z	p-value (2-tailed)
2 and 3	-2.001	.045 *
3 and 4	-2.194	.028 *
4 and 5	-3.099	.002 **
2 and 5	-1.677	.093

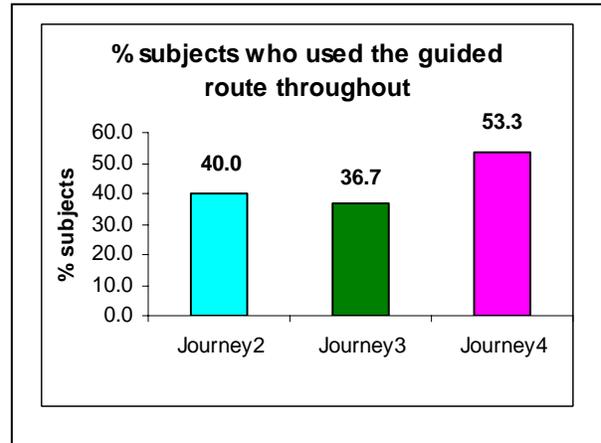
\*= 95% significance: \*\*= 99% significance

### 8.3 Guidance Acceptance

**Figure 5** shows that percentage of drivers who stated to have accepted guidance dropped from 56% to 16% for journeys 2 to 4, indicating a decline in compliance with the increase in network knowledge. Journey 5 in figure 5 is skewed perhaps due to the impact of sub-optimal guidance. Actual compliance as analysed for the optimal route (minimum time path) showed that the percentage of subjects following guidance throughout on optimal route declined from 40% to 37% from journeys 2 to 3. However the percentage increased to 53% for the journey with complete network knowledge indicating that with greater familiarity route choice based on subjects' network knowledge coincided with the optimal guided route (**Figure 6**).



**Figure 5: Stated Compliance for different journeys: Guidance**



**Figure 6: Percentage of subjects with 100% compliance on optimal path**

### 8.4 Compliance as a function of quality of guidance

For journey 5, analysis of compliance was done at critical nodes, which were the crucial points en-route where the drivers, if were using their network knowledge, were expected to have recognized being given duff guidance and could have subsequently taken a better route. It was observed that even though to start with 76.7% of the subjects followed sub-optimal guidance, perhaps due to their good experience with it for the previous journeys, yet compliance to sub-optimal guidance dropped, with only 16.7% of the subjects following sub-optimal guidance throughout. The others did realise its sub-optimality based on local evidence and gave up following it at different points during the journey.

### 8.5 Correlation Analysis:

No significant correlations between subjects' personal characteristics and their journey performance or percentage compliance to these systems were found. However significant negative correlation between gender and stated usage of maps or information for journey 3 indicates that men stated to have used less guidance as compared to women for the journey 3 where the map represented the network layout only ( $\rho = -0.428$ ,  $N = 60$ ,  $P = 0.001 < 0.05$ , two tailed).

## **8.5 Validation of Simulator**

Around 90% of the total subjects stated that simulator gave them a “realistic enough” impression of making a journey by car. The results from Firmin (1995a) show that around 89% of the subjects had qualified the driving experience as realistic enough when TRAVSIM was first validated. Thus the results on realism qualify the simulator as a realistic enough tool to collect data on route choice behaviour as also accepted in past research by Bonsall et al, (1994), Koutsopoulos et al (1995) and Bonsall et al, (1997).

## **9. SUMMARY & IMPLICATIONS OF RESEARCH**

Role of Driver Route Guidance systems in achieving transport system efficiency has been well accepted. Drivers’ response to these systems has been extensively researched and has shown evidence of variability in drivers’ response to compliance with these systems depending on driver’s network familiarity, type of system, quality of advice or information, credibility of the systems and the drivers’ personal characteristics. The impact of network knowledge on response to driver route Guidance, in terms of the variability in compliance with these systems under different levels of network familiarity, was studied using a route choice travel simulator, TRAVSIM, which has been acknowledged as an efficient, inexpensive, easy to use, reliable and realistic tool to collect data on route choice behaviour under controlled experimental conditions.

The results indicated that the increased network knowledge results in reduced reliance on the guidance systems. Drivers’ journey performance, a function of their route choice decisions, in unfamiliar conditions improved with availability of guidance. Results also showed that even though based on good past experiences with such systems, sub optimal guidance could be accepted by drivers, yet based on local evidence and network knowledge they tend to gradually reject sub-optimal guidance. No significant correlations between the personal characteristics of the subjects and the compliance to guidance or the journey performance were found.

The study showed that guidance systems have a market for unfamiliar areas (hire car market) or for novice drivers as the compliance is higher in unfamiliar networks. Guidance systems should be designed to provide optimal guidance based on all short cut links known to potential users to ensure higher acceptability. As network knowledge impacts compliance, it is unlikely to use guidance systems for network optimisation in an attempt to divert traffic from environmentally sensitive routes. The study also implied that for route choice studies, travel simulators can prove to be efficient, reliable and a cost effective tool for data collection.

## **ACKNOWLEDGEMENTS**

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