RESEARCH METHODS FOR THE STUDY OF DRIVER RESPONSE TO IN-VEHICLE AND ROADSIDE GUIDANCE - METHODS

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INTRODUCTION

This paper is concerned with drivers' responses to information or guidance which is intended to assist or influence the drivers' route choice rather than with information and warnings which are primarily intended to influence speed, lane choice and so on. Information systems relevant to this review therefore include: fixed and variable message signs (VMS); open-channel radio broadcasts; hidden/interrupt radio broadcasts (such as the RDS/TMS system); autonomous navigation aids (such as the first generation CARIN DRIVEGUIDE and ETAK systems), and dynamically updated guidance/advice systems (such as Aliscout, SOCRATES, TRAVTEK and ADVANCE). These systems differ not only in terms of the medium of presentation (audio, text, map) but also in terms of the type of message (instructions, advice, information), its currency (whether based on historic average conditions, or recent reports from 'probe' vehicles on the network), and the degree to which it may be tailored to suit the needs of the individual driver.

Current developments are being spurred on by national and supranational initiatives and lobbies (eg. RACS, DRIVE and IVHS America) partly out of a desire to gain a commercial foothold in what is expected to become a very important market and partly out of a genuine belief that systems such as these can provide real benefits to individual drivers and to the transport network as a whole. It has been demonstrated that the benefits are crucially dependent on the assumptions made about driver response to guidance/information and this in turn has emphasised the value of the kind of work reviewed in the current paper.

Drivers may respond to en route information and guidance in various ways; the most important, in the current context, being to change their route choice. Information received en route during one journey may affect behaviour on subsequent journeys - it may, for example, result in a revision of the driver's 'normal' route or departure time and might even affect trip frequency, mode or destination choice. Any study of driver response ought ideally to be capable of picking up all these responses. Changes in driving style may also be important but these, along with other human factors issues, are not the main subject of this paper.

Direct responses to guidance or recommendations can be categorised as 'compliant' or 'non-compliant' (eg. was the recommended route followed or not followed?) but, since a proportion of the driving population might have been going to use that route anyway, the effectiveness of the system can really only be measured in terms of the net change in behaviour. In the case of information systems, the concept of 'compliance' may be of limited validity and, again, it will be the net change in behaviour which is of greatest interest. This being so, studies of driver response will be particularly valuable if they can give some indication of the counterfactual (what would have happened if the information/advice had not been given?). This issue is a recurring theme in the current paper.

There are various ways in which one might categorise the available study methods. I have chosen to differentiate between those that can be used before any detailed design has been conducted, those that make use of mock ups and simulators, those involving pre-implementation trials and those involving post-implementation monitoring and surveys.

1. PRE-IMPLEMENTATION ATTITUDINAL RESEARCH AND STATED PREFERENCE METHODS

These methods can be used to estimate likely response by studying the attitudes and underlying motivations of potential users and, more formally, by using a variety of techniques to explore their reaction to hypothesised choice situations.

Attitudinal and motivational research may involve group discussions, interviews and questionnaires - the former being particularly useful during the early stages where they help to formulate the questions to be put to a wider sample of people via a questionnaire. Research of this kind was employed as part of the DRIVE project CARGOES (Bonsall and Parry, 1990) primarily in order to discover drivers' requirements for route guidance and information but the results also throw interesting light on potential responses. Another well documented use of pre-implementation attitudinal and user preference research was recently conducted in Seattle as part of the design study for a commuter information system (see Haselkorn et al, 1991). This study involved mailback questionnaires and telephone surveys to gauge users' reactions to examples of different types of information presentation and included questions relating to potential behavioural responses to the different presentations.

Although the absolute value of answer to the simple question 'Would you follow advice from a guidance system like this?' is of interest, it cannot be expected to be a reliable guide since it is not reasonable to expect someone who has no personal experience of the system to have formed a view on the trustworthiness of the advice nor to be able realistically to imagine the circumstances in which he would actually have decide whether or not to comply with the advice. Much more is to be gained by examining the relative values of compliance quoted by different types of driver and for different types of circumstances (eg. on a familiar route or an unfamiliar route, when the advice is produced via an on-board computer or broadcast over the radio and so on).

A more formal approach to this could involve use of stated preference (SP) methods. An interesting example of which was some work in connection with the Amsterdam VMS system reported by Brocken and Van der Vlist (1991); they used a mail-back SP method to explore drivers' reactions to a number of choice situations in which alternative routes had different characteristics with respect to distance, time and congestion. The SP method involves construction of a set of choice situations where the options exhibit carefully designed combinations of attributes. Analysis of the respondents' choices can then be used to derive (by various methods, including logit and regression modelling) underlying preference structures and thus provides a basis for predicting behaviour.

The Amsterdam SP study did not seek directly to gauge drivers' responses to route guidance or information but there is not technical reason why an SP study should not extend the range of route attributes to include factors such as presence/absence of recommendations or warnings provided by a hypothesised guidance or information system. It is by no means clear, however, that the results from such an exercise would be reliable given the artificiality of the circumstances, particularly if the respondents have limited background knowledge and experience of the guidance system being 'tested'. This problem of limited background knowledge and experience with certain sorts of system can be reduced by exposing the respondent to descriptive material, including photographs, short video presentations and prototype equipment but it can not be eliminated; particularly because no amount of descriptive material can substitute for the personal experience upon which a driver would base his idea of the credibility of the system. In view of the above, SP is likely to give less reliable results for a novel system such as one of the new in-vehicle route guidance systems, than for a system (such as radio broadcasts or static roadside signs) with which drivers are already familiar.

Despite their limitations, pre-implementation attitude surveys and stated preference exercises can be a very effective, and remarkably cheap, way of making an initial estimate of likely response and as such they are particularly useful during the predesign phase of a project.

2. PRE-IMPLEMENTATION STUDIES USING MOCK-UPS AND SIMULATORS

Use of mock-ups and simulators is justified by the fact that it is only when the decision environment is realistically portrayed that the responses are likely to be reliable. The problem, of course, is that simulators tend to be expensive and sessions with them tend to be time consuming - thus effectively limiting the sample size achievable.

2.1. Driving simulators

The most sophisticated simulators incorporate a realistic driving cab (often based on the shell of a real vehicle) instrumented so that the driver's use of the various controls is reflected in computer controlled motion (in three dimensions), graphic images and sound. Associated databases enable the 'vehicles' to be 'driven' in real networks. Examples of such top-of-the-range simulators include those owned by

Daimler-Benz, the Swedish Road and Traffic Research Institute (VTI) and the Hughes Aircraft Corporation. Such devices could be used to study driver route choice in response to guidance and advice but their real strength lies in the potential for human factors research which, in our context, might include the effect that receipt of information or guidance in various forms might have on performance of the driving task (measured at various levels - eye movements, heart rates, reaction times, position of the vehicle on the road, etc). It is to be hoped that such devices could be 'borrowed' for studies of route choice responses to guidance and information but economic realities make this a somewhat doubtful prospect.

The cost of a simulator is much reduced if it does not incorporate motion. There are many examples of such fixed-cab simulators which nonetheless incorporate sophisticated representation of the 'outside' view and the ability to drive at will through a real network. Despite their lack of a sense of motion they can provide a very satisfactory representation of driving (particularly inter-urban driving) and clearly have a role in testing route choice responses to information and guidance. Brocken and Van der Vlist (1991) describe the use of the TNO simulator (which is of this type) to study responses to various designs of VMS. There is clearly great scope for using such simulators to study route choice behaviour and several institutions, my own among them, are actively preparing to do such work. Most work to date, however, has been concerned with human factor aspects - recent work with the FHWA's HYSIM driving simulator for example, was concerned with the safety implications of six different types of in-vehicle guidance-advice system (see Walker et al, 1991).

Very useful work on human factors issues has also been conducted using 'rolling-road' simulators which incorporate a video of a journey along a given stretch of road. However, given the limited potential which such simulators have for route choice, their contribution to studies of this aspect of response is effectively limited to the divert/not divert decision. Although the divert/not divert decision is important (particularly in the context of guidance systems based on major roads), it is only a part of the total behaviour pattern. It may for example, sometimes be important to know which route a driver would take after he has diverted off a main road even if the information system itself has no role beyond the main roads.

An interesting and much cheaper alternative to a 'proper' driving simulator might be to adapt one of the driving task games available in games arcades or for use on home computers. Bright and Ayland (1991) adopted this approach within the EURONETT project taking as their starting point a commercially produced home computer game which involved racing a car through an urban network. The game was linked to a series of external devices to represent, respectively, a base map location display - as per Bosch TravelPilot, audio directional advice - as per Aliscout and a RDS-TMC system providing information about traffic conditions. Separate measures of driver performance were calculated for each system together with an overall measure of 'success' in navigating through the system. Despite its obvious appeal as a cheap driving simulator the artificiality of the driving task (not least keeping the vehicle on the road!) must reduce its usefulness.

2.2. Part task simulators

A problem with all the above simulators, which rely on computer generated perspective images of the road view, is the difficulty of representing congestion. Given that congestion is known to have an important influence on route choice decisions this is a serious drawback. The problem has been addressed, in rather different ways, by three simulators which were developed specifically to study route choice aspects of driver response to guidance and advice. They are the IGOR simulator, the Systems Technology Inc (STI) simulator and the FASTCARS simulator.

The IGOR simulator (see Bonsall and Parry, 1989) was designed to collect large volumes of data in the field and was therefore written to run on a portable PC and the driving task was simplified to comprise only route choice decisions at junctions. The user is invited to make a series of journeys through hypothetical networks subject to varying traffic conditions. At each junction the computer displays birds-eye information on site layout and traffic conditions (including any congestion visible on exit arms), and provides directional advice as per Aliscout. The advice normally identifies the quickest route to the current destination but, unknown to the users, the advice is sometimes deliberately degraded so that the influence of advice of different qualities could be assessed. Details of each situation faced and each decision taken by the driver are stored, together with details of the driver's age, sex, driving experience, stated route choice criteria etc, for subsequent analysis. The portability of the IGOR simulator (it fits onto a notebook PC) has made it possible to assemble a large data set (over 700 individuals in the UK, France, Greece and the Netherlands as of January 1992). The speed with which each journey can be completed has made it possible to get each driver to make several journeys with and without guidance, this has enabled analyses to be conducted of route choice with and without guidance and of the effect that past experience of a network (and of route guidance of different qualities) has on compliance (see Bonsall and Joint, 1991).

The STI simulator (Allen et al, 1991) differs from IGOR most dramatically in being based on a real network and in providing road views via photographic slides of appropriate stretches of the network. Players are invited to make journeys within part of the Orange Country network and while they do so it displays a sequence of slides appropriate to the route chosen. Four different types of guidance system are represented on a computer screen (directional advice as per Aliscout; locational map as per basic ETAK; locational map plus representation of congestion; and an advanced system with congestion and an advised route shown on a map and information about upcoming congestion provided via an audio channel. Different sequences of slides showing different levels of congestion allow responses to advice to be assessed in different congestion scenarios. The main thrust of the work with the STI has been on the different diversion rates obtained with the different types of guidance/information system.

The FASTCARS simulator (Adler, 1991), like IGOR, is based on a hypothetical network but it differs radically in its treatment of the time dimension. IGOR compressed time on links into an instant by taking the user directly from one junction to the next and put no constraint on the length of time taken to make a decision at each junction. FASTCARS, on the other hand, is much more faithful in its representation of time; the user spends most of his time on links and, as junctions are approached, action must be taken to divert if so desired. This is obviously a more sophisticated treatment than IGOR's but, given the fundamental artificiality of the environment, it is not necessarily the case that it will result in more realistic route choice behaviour. FASTCARS was designed to examine route choice behaviour in a quite detailed manner and, in conjunction with this, incorporates a reward/penalty system based on the achievement of multi-attribute goals (specified in terms of time minimisation, on time arrival, diversion avoidance and so on - weighted to reflect the players' stated priorities). FASTCARS is currently configured to represent three alternative forms of guidance; VMS, HAR and directional advice as per Aliscout.

IGOR, the STI simulator and FASTCARS all concentrate on route choice responses and their representation of other aspects of the driving task is simplified to a greater or lesser degree, in this respect they qualify as part-task simulators rather than full simulators. Other part-task simulators have concentrated on human factors aspects rather than on route choice responses. A particularly sophisticated example being the GIDS system (Godthelp and op de Beek, 1991) developed under the DRIVE initiative. Some very useful work to study drivers' abilities to understand different forms of guidance and information messages has been conducted using physical mock-ups of different types of system and requiring subjects to undertake artificial primary activities as a proxy for the driving task (see for example, Stephens, 1990).

3. ON-ROAD TRIALS USING PROTOTYPE EQUIPMENT

Once a prototype of an in-vehicle system exists, much can obviously be gained by obtaining or observing drivers' reactions to it in the context of real journeys. Human factors issues are obviously to the fore in such exercises and this is often recognised by designating them as 'usability trials'. Recommendations stemming from such trials typically relate to ergonomic aspects of the layout of in-vehicle equipment problems with understanding instructions and so on (see for example Collins, 1989).

Methods used during prototype trials include debriefing interviews and questionnaires following one or more test drives, human observers accompanying the driver on a 'test' drive and noting his/her reactions, and (semi-)automatic monitoring via instrumentation of the vehicle (eg. to record use of controls) and of the driver (to detect eye movements, stress levels etc) and monitoring of the road scene (eg. using through-windscreen video). A valuable account of the use of such techniques in a comparative study of different types of in-vehicle advice system is provided by Parkes et al (1991).

A certain amount of market research is often carried out in conjunction with prototype trials but, since it is not normally economic to involve large numbers of drivers in these trials, sample sizes are rarely adequate to derive anything valuable about behavioural response (except in so far as it relates to human factors - such as an inability to understand or act on the advice).

There is a lively debate as to the relative merits of on road trials and of full scale driving simulators. Provided that the instrumentation is not intrusive the on-road trial is more 'realistic' but it is not so efficient in terms of experimental design (arranging for the drivers to be put in a range of situations), cannot be undertaken at so early a stage in the design and, ethically, cannot be used to test systems which may not be safe.

4. POST IMPLEMENTATION STUDIES

We turn our attention now to those methods that can only be used once a system has been implemented and a population of 'users' can be identified. If the population of 'users' is large (as with road-side systems or public broadcast systems) there will be a choice between aggregate studies (eg. involving measurements of changes in flow) and studies of individual drivers' responses. If the population of users is small (as it will be, in the early stages at any rate, in the case of advanced in-vehicle systems) aggregate monitoring would be fruitless and studies of individual response are necessary. We will consider individual studies in Section 4.1 and aggregate studies in Section 4.2.

4.1. Studies of individual drivers' behaviour

The possibility exists, in theory at any rate, automatically to monitor the behaviour of drivers provided with certain types of route guidance. Systems (such as Aliscout and SOCRATES) which use equipped vehicles as probes with which to sample current traffic conditions involve vehicles reporting back their position to a central computer. Provided the records are kept and privacy issues aside, it may sometimes be possible to use records of the messages sent by vehicles to the computer to reconstruct routes taken by individual vehicles and to compare these with advice being offered to the driver. In practice, however, as the author can testify, this procedure can be laborious in the extreme and, unless the need for it is foreseen at the system design stage, it may prove impracticable.

An alternative procedure, which would avoid the time-consuming business of locating the messages associated with each vehicle, might be to instrument a sample of vehicles to monitor the messages passing in and out of the vehicle and to store them (eg. on a cassette or disc) for later analysis.

If automatic means are not feasible, the best option may be to arrange for drivers to keep their own records. This method was used in Berlin by ITS to study route choices and journey times by drivers equipped with the LISB Aliscout system. Two variants were used; one involved providing drivers with tape recorders on which they were to record routes taken on particular days and the other involved asking them to reconstruct routes taken by listing the streets used or tracing their routes on to a base map (Slapa and Bonsall, 1990). The advantage of the tape recorder method is the greater accuracy and detail - the data is recorded at the time and the driver can be asked to add a commentary on the advice received and the reason for deciding to ignore or comply with it. The advantage of the hard copy method is the lower cost in terms of equipment and processing time and the feasibility of larger sample sizes.

Data obtained by monitoring individual journeys is, of course, particularly valuable if behaviour relating to a known range of situations (including some where no guidance or information was provided) is included. If manipulation of the field trial to 'create' such possibilities is not possible then use should be made of 'before' and 'after' monitoring or control groups.

Since certain human factors issues are likely to have remained unresolved after the prototype trials (eg. due to limitations of the sample size at that stage or due to continued product development) it may be appropriate to reintroduce such issues during the field trial. Automatic monitoring may yield some information (eg. on erratic speed profiles) that can be related to the driver's ability to perform the driving task but the main source of information is likely to be the debriefing interview or questionnaire.

Questionnaires administered after the driver has gained several weeks of experience with the system can be used not only to probe human factors issues but also, more generally to ascertain attitudes and generalised responses (eg. an indication of the circumstances in which they normally do, or do not, comply with advice and an indication of any changes in journey timing, frequency etc). Questions can also be asked relating to their responses on specific journeys (eg. the most recent one or, since it is likely to have been more memorable, a recent journey to a previously unknown locality). Such answers can be particularly revealing if the responses can be tied up with automatically monitored records relating to the same journey. Questions of this sort were used as part of the evaluation of the LISB system in Berlin where a panel of equipped drivers completed questionnaires at various stages during the scheme (see Slapa and Bonsall, 1990 and Joint and Bonsall, 1990). Interviews used for a similar purpose are, of course, more expensive and potentially subject to certain types of bias but can yield more detailed data if such be needed.

As was indicated above, driver response to mass-exposure systems such as roadsigns and public broadcasts can be studied at the individual or the population level. At the individual level this will be most effectively done by means of questionnaires or interviews targeted at the exposed population. Even for general studies it may be appropriate to target users of a particular stretch of road at a particular time because , by so doing, 'noise' due to variable external factors can be reduced and the possibility of examining responses to a particular, temporarily displayed sign or one-off broadcast message, is created. The target population might, in such circumstances, be most effectively approached via roadside interviews, distribution of mail-back questionnaires at stop lines or use of vehicle registration numbers in order to identify drivers to whom a questionnaire might be sent. Questions to be asked might include human factors issues (such as whether a particular sign message was seen/heard, whether the message was legible/audible and how it was interpreted) as well as whether it caused a change in behaviour. Answers could be related to information provided on the socio-economic characteristics of the individual and details of the journey being undertaken. The opportunity might be taken to extend the range of questions to explore the individual's attitude to particular types of sign or message and his view of their relative utility and credibility. It might also be appropriate to include some stated preference questions to explore the individuals' possible response to alternative types of sign or message.

These more general questions do not, of course, need to be targeted to users of specific stretches of road at particular points in time and alternative sampling strategies may be more appropriate (residents of a particular area, drivers of particular types of vehicle, people with particular disabilities, etc).

There are of course numerous examples of surveys of this kind. The following list indicates something of the range of applications over the last two decades: Heathington et al (1971) studied drivers' route diversion behaviour and attitudes; Turner et al (1978) studied diversions associated with freeway maintenance operations; Dudek et al (1978) studied drivers' responses to temporary special event signing; Owen (1988) studied responses to broadcast traffic information; Wootton et al (1981) studied the effect of static roadsigns on driver route choice; Shirazi et al (1988) studied commuters' attitudes to traffic information systems, and Khattak et al (1991) studied drivers' responses to broadcast traffic messages. Questionnaire based investigations of drivers responses to variable message signs are still rare; an important study conducted recently by INRETS involved approximately one thousand roadside interviews at off-ramps from the Paris motorway network in order to gauge drivers' reactions to the various forms of VMS recently installed there.

4.2. Studies of aggregate behaviour

When a large part of a population of drivers has been exposed to a particular sign or message it will generally be cheaper to measure aggregate impacts than to examine individual behaviour and then to aggregate this up via models. Impacts can, of course, only be deduced by comparing the with-message and without-message situations. This will usually involve a before and after study of some kind or, if possible, a deliberate manipulation of the situation so as to control for other potential influences.

Easily measured aggregate quantities indicative of changes in route choice and potentially of changes in trip rates, journey timings and so on, include flows downstream of divergence points and origin-destination route-splits. Flows can be monitored continuously to detect the influence of the presence/absence/past presence of messages and, with the latest generation of vehicle-classifying equipment it is theoretically possible to detect different impacts on different types of vehicle. Determination of O-D patterns (and hence O-D splits) may be possible by matching vehicle registration records and, by means of matrix estimation techniques, by flow monitoring at critical points on the network. Some early studies (eg. Albecht's (1978) study of driver response to directional VMS on autobahns in the Rhine-Main area and Dudek's (1982) study of response to temporary event signing) showed how difficult it could be to detect and attribute changes in flow unless there was reliable data on ambient variability and underlying O-D patterns. It was, for example, not possible to say whether the 8-10% diversion observed in the Rhine-Main case represented a high or a low percentage of the potentially divertable flow. Current monitoring programmes (eg. that on the Paris motorway network) will hopefully be able to overcome such problems given the availability of much richer databases.

Various aspects of driving behaviour can also be measured in aggregate; speed is the most obvious example but it should also be possible, using video techniques combined with automatic image processing software, to obtain continuous data on such things as headways, decelerations, and lane changing.

5. CONCLUDING REMARKS

This review has indicated a wide range of potential methods for studying drivers' responses to route guidance and information systems. It has been seen that different techniques are appropriate to different stages in the process of designing, refining and evaluating a system and that the choice of method will also depend on the types of question being asked and the type of system being investigated. Indications of the ways in which an assessment of user response might fit into an overall post-hoc evaluation of a particular route guidance system are provided in May and Bonsall (1989) and in Lesort et al (1991).

Pre-implementation assessment of user response is, of course, particularly valuable since it can be used to help in the design specification/refinement, but any such assessment is open to challenge - how do we know that users will respond in such and such a way? It is sometimes possible to point to evidence from past implementations but such evidence may not exist for some of the most advanced systems and it will therefore not be possible to 'validate' predictions based on the use of simulators and other pre-implementation techniques as fully as one might wish. For the benefit of those who will use such techniques in the future it is important to make sure that validations are conducted as soon as possible. Unfortunately the political will (and cash) required to validate predictions has a habit of evaporating once the 'real' data exists.

The attraction of using evidence of user response from one implementation as the basis of predicting the response in another is obvious. But transferability cannot be guaranteed even if the system specification is identical; different cultural responses to authority, to 'official' advice, and to the credibility of technology can obviously affect compliance but so too might more subtle factors such as local experience of the predictability and extent of congestion and perceptions of the road hierarchy. It is therefore important, not only to measure response but also to attempt to understand it. It is only by understanding the underlying causes of particular response patterns that one is likely to be in a position to indicate how responses might differ in different circumstances. This is the justification for continued research into the use of simulators and other advanced techniques to measure individual response.

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