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DRIVERS' RESPONSE TO IN-VEHICLE ROUTE GUIDANCE INFORMATION SYSTEMS: AN EXPERIMENT WITH A MOCK-UP GUIDANCE SYSTEM

NM Gotts
PW Bonsall

ABSTRACT

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The paper reports an exploratory study, using an unusual technique to investigate drivers' response to in-vehicle route guidance information systems. Eighteen drivers were recruited, and asked to make a series of three trips in an unfamiliar area. Each driver was given turning advice, via a speech synthesiser, on one of these trips. This advice was based on average traffic conditions for the time of day. Unbeknown to the drivers, the advice was in fact triggered by the experimenter, who was riding as a back-seat passenger. Details were kept of times and routes taken with and without guidance, and with different levels of network familiarity. Records were also kept (using questionnaires and video and audio recording) of planning and route-following strategies.

As expected, both receipt of guidance and even very rudimentary network familiarity resulted in reduced journey times, and routes closer to the guidance recommendations. The study indicated that factors including the directness of possible routes, their perceived complexity, and familiarity all affect route choice, but to different extents for different individuals and under different circumstances. Error was shown to be important in determining the route actually followed when guidance was withheld. The study showed that giving in-vehicle guidance using the mock-up technique described is practicable, and does influence drivers' route-choice and route-following behaviour. A possible future study is outlined, aimed at identifying the determinants of the drivers' level of compliance with advice when they believe that advice is based on *real-time* traffic information.

Key words: in-vehicle, route guidance, travel information, driver response

Contact: Nick Gotts, Institute for Transport Studies (tel: 0532-335342)

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DRIVERS' RESPONSE TO IN-VEHICLE ROUTE GUIDANCE INFORMATION SYSTEMS: AN EXPERIMENT WITH A MOCK-UP GUIDANCE SYSTEM

1.INTRODUCTION

1.1.BACKGROUND

This paper describes an exploratory experimental study of drivers' route-choice strategies and route-following performance under a range of conditions, including the provision of advice from a mock-up of an automatic route guidance system. This mock-up consisted of a portable speech synthesizer, programmed with guidance messages that could be surreptitiously triggered by the experimenter. The study was carried out in Leeds in July 1992. The work reported was carried out as part of the SERC Rolling Programme "Fundamental Requirements for Full-Scale Dynamic Route-Guidance Systems", and complements other work we are carrying out on the behavioural aspects of route guidance systems.

One of the fundamental requirements for the successful design and implementation of such In-Vehicle Route Guidance and Information (IVRGI) systems is an improved understanding of the wayfinding strategies drivers adopt when such a system is available - and, for comparative purposes, of their strategies in the absence of such a system. Better understanding of human response to IVRGI systems will aid both the process of designing such systems, and that of modelling the effects on traffic flow of introducing such a system in particular networks.

Understanding driver response to automatic route-guidance and similar systems can be approached by considering such a system as one among a range of information sources available to the driver (see Gotts 1992, especially section 3). In addition to current perceptions of the network, these may include the driver's memory of network structure and dynamics, maps, prepared lists of instructions, and directions from passengers and passers-by. Drivers will presumably choose from among these sources according to their judgements of the relevance and credibility of the information they provide, the effort required to access relevant information, and conflicts or corroboration between sources.

Given this way of conceptualising the response to guidance systems, we can view the degree of *familiarity* the driver has with the network as one type of variation in the set of information sources available to the driver. The more familiar an area is, the more relevant information is likely to be available from the driver's long-term memory. This study compares subjects' first and second attempts at a particular wayfinding problem, as well as attempts made with and without guidance.

1.2HYPOTHESES TO BE TESTED

A range of specific hypotheses was investigated concerning the effects that the availability of guidance, and network familiarity, would have on the performance of the wayfinding task. In particular, it was hypothesised that by enhancing the information sources available and thereby reducing task difficulty, both the provision of reasonably good guidance and network familiarity would:

•reduce trip times;

•reduce the number of halts made on the trip;

• reduce the number of U-turns made on the trip;
•reduce negative mood shifts during the trip;
•bring the drivers' routes closer to those recommended by the guidance system.

It was also hypothesized that:

•the availability of guidance and the possession of prior knowledge of the network would each reduce the perceived need for planning and thus would reduce pre-trip planning time;
•trip time would be influenced by the amount of time devoted to pre-trip planning.

The study gave rise to a broad range of observations concerning drivers' behaviour and comments with and without access to automatic guidance and to the memory of a previous trip. These can be divided into three main topic areas: pre-trip planning, particularly the criteria for route choice which drivers adopt; the causes and consequences of error in following planned routes; and the drivers' response to the mock-up guidance system, especially the conditions governing whether they complied with its advice.

2.METHOD

2.1QUESTIONS OF VALIDITY

Existing techniques for investigating drivers' response to IVRGI and similar systems include both the use of questionnaire and survey techniques, and experimental approaches (see Bonsall 1992 for a review). The experimental approach in turn includes the use of travel simulators such as IGOR (Bonsall and Parry 1990), and full-scale field trials of working IVRGI systems (e.g. Bonsall and Joint 1991). These two experimental techniques make very different trade-offs between realism (and so the confidence one can have in the validity of results) on the one hand, and cost on the other; the current work was stimulated by the belief that there might be room between them for a third approach, similar to that adopted in studying response to broadcast traffic information by Owens (1980).

Testing existing systems is clearly both the most realistic approach, and the most costly. Its use is limited by the small number of IVRGI systems in operation. In contrast, travel simulators allow the collection of a large amount of data at low cost, and for this reason have formed the mainstay of our work thus far. However, the validity of data derived from such simulators can obviously be questioned: do they really present the subject with a task sufficiently similar to real route-choice problems to evoke similar responses and strategies?

There is no *definitive* way to check the validity of results obtained from route-choice simulators, other than to retest the results in parallel real-world route-choice studies. If sufficient results from such real-world studies could be gathered at acceptable cost, of course, there would be no need for the simulation studies! However, we can make an informed assessment of the validity of simulator data by judging the relevance and integrity of simulator design in the light of the existing literature, and by making what checks we can against studies of drivers' behaviour during real travel.

Mock-up studies are closer to "real life" than simulator studies, but once again, questions of validity can be raised: we cannot be certain that drivers will respond in the same way to a mock-up system as to a real one, even if they do not appear to detect the nature of the mock-up. (If they do detect that the experimenter is triggering the guidance, of course, biases could result.) As with simulator studies, the validity of mock-up techniques can only be assessed definitively by comparing results in experiments using mock-ups with those using real guidance systems. However, if we make our mock-ups as realistic and relevant as possible in the light of existing knowledge, and if results are consistent and conform to common-sense expectations in simple cases, we may provisionally assume a useful degree of validity. The hypotheses concerning the effects of guidance and familiarity investigated in this study are all at this simple level, being intended to act as a test of the technique before applying it to more difficult studies in future. In future research, we contemplate using the simulator and mock-up techniques in tandem. If subjects in the two types of study appear to behave very differently in parallel situations - to use very different criteria in selecting routes, for example, or to respond very differently to making an error - doubt would be cast on the validity of both techniques. Conversely, consonant findings should enhance confidence in both approaches.

2.2OUTLINE DESCRIPTION

In the first phase of the study, subjects were recruited and asked to indicate the areas of Leeds in which they currently lived, worked, and/or travelled regularly. In the second phase, all subjects were given the problem of driving from one point (O_A) to another (D_A) in an area of Leeds relatively unfamiliar to them. They were provided with a street map, and opportunity to plan their route if desired. After the second phase, subjects were paired according to the similarity of their O_A-D_A routes. In the third phase, each subject was given two problems successively: first, driving from O_B to D_B (again, the area between these points was relatively unfamiliar to all subjects); then driving from O_A to D_A again. Each subject was given guidance from the simulated automatic guidance system on one of these two trips: one member of each pair on the first trip, from O_B to D_B, the other member of each pair on the second, from O_A to D_A. Each subject therefore made three trips, referred to as Trip0 (O_A to D_A), Trip1 (O_B to D_B), and Trip2 (O_A to D_A again). Trips were recorded on video, and audio tapes were made of subjects' pre-trip planning. Subjects filled in questionnaires after each trip.

2.3SUBJECTS

Subjects were recruited by placing advertisements, offering £15 for participation in the study, in locations around Leeds University; and in a few cases by personal recommendation. A total of 25 subjects (7 female, 18 male) were recruited, but 7 dropped out, leaving 18 (5 female, 13 male). Each subject was asked on recruitment to fill in a form concerning their personal details and driving experience. The subjects had a mean age of 24.4 years (S.D. 6.0 years, range 19-42 years); mean continuous residence in Leeds of 8.2 years (S.D. 10.5 years, range 0-32 years); and mean driving experience of 5.8 years (S.D. 4.2 years, range 2-16 years). 9 of the 18 were undergraduate or postgraduate students, 5 were unemployed, the remaining 4 were employed.

2.4SELECTION OF O/D PAIRS

We wanted to give the drivers wayfinding problems which would be sufficiently difficult to generate errors, and to give the subjects an incentive to make use of guidance when available. However, it was hoped to keep the time for a single trip down to no more than 30 minutes. O/D pairs were selected to minimise the degree to which any of the subjects would derive possible advantages from familiarity with the area of travel, using the information subjects gave about their

Leeds travel experience in the first phase. The two O/D pairs were so located that network experience gained on one would not be useful on the other.

2.5THE GUIDANCE SYSTEM

We decided to emulate a guidance system giving turning movement advice which, if followed, would lead the driver to the destination by the quickest route *assuming average traffic conditions for the time of day*. Time-minimising turning movement advice was therefore required at each junction a driver might reasonably go through en route from the specified origin to the specified destination.

A guidance system based on average traffic conditions is referred to as a "static" guidance system, as opposed to a "dynamic" system, in which guidance is based on information about current traffic conditions, collected from equipped vehicles and/or roadside cameras. We chose to emulate a static guidance system, and present it to subjects as such, because we had no way of accessing the necessary traffic information in real time, and convincing subjects that a guidance system is dynamic when in fact it is static presents considerable problems. In trying out a novel technique, it was judged best to avoid these.

For technical and safety reasons, it was decided that guidance should be spoken rather than presented visually. The synthesized speech used was produced by a specialised computer, the Lightwriter SL30, manufactured as a communication aid for people without speech.

The set of advisory messages to be given by the guidance system at particular points in the network was constructed as follows.

1)For each of the two O/D pairs, a region was chosen, containing both origin and destination and rectangular-to-oval in shape, outside of which advice was *not* to be given.

2)A SATURN model (Van Vliet 1982) of traffic flow in Leeds during off-peak periods was run, using 1988 data generously supplied by West Yorkshire Highways, Engineering and Technical Services Joint Committee (HETS) to produce estimates of the mean travel-times (in both directions) for each link within either of the two guidance regions that was represented in the HETS network (which did not include all minor roads). The density of the SATURN networks relative to the complete road networks in the same areas is shown on Map 1 (for the network including O_B and D_B), and Map 2 (for the larger network including O_A and D_A).

3)For each of the two destinations, a tree of minimum-time routes to that destination was constructed, covering journeys starting from all nodes within its guidance region and included in the HETS network. Together with the links joining them, these nodes made up the "guidance tree" for the destination.

4)These trees could have been translated directly into a set of "recommended exits" - one for each guidance node - but for one complication: for reasons of safety, it was decided that the guidance system should never recommend making a U-turn in the road - either at or between nodes. Only in the case of a roundabout would the guidance system ever advise the driver to leave a node by the same link used to get there. For all guidance nodes other than roundabouts, therefore, a second recommended exit had to be selected (again on a minimum-time basis) in case the driver approached the node via the link that would otherwise be the recommended exit.

5)A set of 29 simple verbal messages was devised (see appendix 1), sufficient to direct the driver to the correct exit when approaching any node while on the guidance network. Each message was assigned to a single key of the Lightwriter SL30, allowing it to be spoken in response to an unobtrusive button-push.

6)For each guidance node, messages that would direct the driver to the correct exit from each possible direction of approach were worked out. Two points are worth noting here.

First, subjects were informed that if they received no explicit guidance, they should assume "carry on as you are going" as a default. This cut down the number of messages required on a journey considerably, mainly by making it unnecessary to include a "Go straight on" message for each side-turning off a major road.

Second, where messages were required, the best message or (occasionally) combination of messages to produce unambiguous advice had to be selected. To give an example, if the driver needed to be directed down one of several left turns leaving a main road in quick succession, the combination of messages used was "Be ready to turn left" some 50-100 yards in advance of the required turn, followed by "Next left" when just passing the turn immediately preceding the target.

7)For each of the two O/D pairs, a map was produced for the experimenter's use, showing which Lightwriter keys should be pressed at just which points on the guidance network.

2.6EXPERIMENTAL PROCEDURE

The study was carried out during July 1992. During the first (recruitment) phase of the study, each subject was given an explanation of its general nature, and two later appointments were made, as near as possible one week apart, for the second and third phases of the study. These appointments were made for daylight off-peak periods, with starting times of between 10am and 2.45pm, or from 6.15pm onwards.

In the second phase, each subject was invited to take the wheel of the experimental car, and verbally directed to O_A by the experimenter prior to beginning Trip0. The subject was asked to "Please indicate the word that best describes your mood now", given the alternatives "angry", "nervous", "relaxed", or "happy", then shown O_A and O_B on a street map of Leeds. He or she was then provided with (unlined) paper and a pen, and invited to plan the journey, writing or sketching if desired. Subjects were encouraged to "plan aloud", and whatever they said at this stage was audio recorded. They were also told that they could stop at any time during the journey to consult the map provided, their own sketches or notes, or passers-by, but that the experimenter would give no advice on the route. They were told that there was no time limit on their trip, and were strongly urged to take no action they felt could endanger themselves or others. No time limit was placed on their preparations. Just before the start of the trip, each subject was encouraged to "think aloud" during the trip. The experimenter occasionally prompted the less voluble subjects with questions about their choice of route.

At the end of the trip each subject was again asked to indicate which of the four words best described their mood, then given a questionnaire to complete. This covered whether the subject had planned the trip in advance, and if so, what route-choice criteria were used; how and with what degree of difficulty they had found their way to the destination; and what type of road or traffic information they thought they would have found most useful. Appendix 2 contains copies of the questionnaires used, along with other documentation used in the study.

The 18 subjects who completed phases 1 and 2 were paired before phase 3 of the experiment, in order to control for individual differences in route-choice and route-following methods as far as possible. The pairing was done on the basis of the similarity of the routes they had followed during Trip0. The way in which route-similarity was calculated is explained in Appendix 3.

Once similarity scores for all the 153 pairs of Trip0 routes had been calculated, pairs with high similarity scores were matched with each other. It was later discovered that the pairing adopted did not quite maximise the intra-pair similarity scores: two changes in pairings would have slightly increased similarity scores.

One member of each pair was assigned to each of two treatment groups at random. Recall that phase 3 of the experiment involved each subject in two trips: Trip1, using a new O/D pair, O_B-D_B (considerably closer to each other than O_A and D_A), and Trip2 on O_A-D_A again. One of each matched pair received guidance on Trip1 and no guidance on Trip2 (treatment group T1G), the other was guided on Trip2 and not on Trip1 (treatment group T2G).

Before each trip, subjects were given a short written explanation of what would happen (see appendix 2). In the case of the guidance trip, they were also given a brief demonstration of the guidance system's voice, to accustom them to its slightly peculiar pronunciation and intonation. It was stressed to these subjects that they were free to follow the guidance or not as they preferred, and that even if they went against it at one junction, they would continue to receive further guidance provided they were still on the guidance network. In both conditions, matters then proceeded as for Trip0: the subjects were given paper, pen and time to make any notes or sketches they liked, recorded while planning aloud, and allowed to set off when they wanted, being encouraged to talk through their decision-making during the journey. On the guidance trip, of course, they received guidance as appropriate. The experimenter sat in the back of the car during these trips (as indeed for all trips), and could not be seen by the driver to be pressing buttons in order to produce the guidance. After each trip, the subject was again given a questionnaire: identical to that used with Trip0 in the case of the unguided trip, augmented with additional questions about the use made of the guidance system on guided trips.

2.7COSTS

Monetary costs of the experiment totalled a little under £1,000. The entire study required approximately 7 person-months including planning, experimental work, and analysis and write-up (£10,500 assuming a £1,500/month cost of employing a researcher), but this could be reduced markedly in any subsequent similar study, as much of the work could be done considerably faster with the advantage of experience. An indication of equipment costs is given in appendix 4.

2.8SAFETY

A number of subjects kept the map, or their own sketch or instructions, open on the passenger seat, glancing down at it while driving. Clearly, this practice should not be encouraged, but the subjects adopted it so readily that it appeared to be part of their normal behaviour. Preventing them from using it might severely disrupt their normal problem-solving procedures. It was decided to permit the subjects to continue using this method, unless it appeared likely to prove dangerous. In fact, it was at no point felt necessary to intervene.

3.ANALYSIS

3.1OVERVIEW OF DATA COLLECTED

For each subject (with minor exceptions for a few subjects due to procedural errors), the following data and materials were available for analysis:

1)A recruitment questionnaire (personal details, plus length of residence in Leeds and of experience as a driver).

2)A map of Leeds showing the approximate location of home and workplace, and which other parts of the city were regular travel areas for the subject at the time of the experiment.

3)Answers to questions about mood before and after each trip (three pairs of answers for each subject).

4)An audio record of the subject's pre-trip planning for each trip (if anything was said by the subject on that occasion).

5)For each trip, any sketch and/or instructions the subject created before the trip (these productions were occasionally modified during the trip). (See appendix 5 for examples.)

6)A video recording of each trip.

7)Three post-trip questionnaires, one filled in after each of the three trips.

3.2TESTING OF SPECIFIC HYPOTHESES

Recall that each member of treatment group T1G was paired with a member of T2G on the basis of similarity of the route taken on Trip0. Each of the 18 subjects made three trips, and the complete set of 54 trips can be divided into six sets of nine by trip number (Trip0, Trip1 or Trip2) and subjects' group membership (T1G or T2G). Hypotheses concerning the effects of prior experience and guidance set out in section 1.2 were investigated, using paired-sample statistics, as follows:

1)The effects of previous experience alone (having solved the problem presented once before, approximately a week ago) on the dependent variables were tested by comparing data from Trip0T1G with Trip2T1G, matching each subject's two trips against each other.

2)The effects of guidance in an unfamiliar network were tested by comparing Trip1T2G with Trip1T1G, matching each subject in T1G with their partner in T2G.

3)The effects of guidance in a previously traversed network were tested by comparing Trip2T1G with Trip2T2G, matching each subject in T1G with their partner in T2G.

4)The effects of guidance combined with familiarity were tested by comparing Trip0T2G with Trip2T2G, matching each subject's two trips against each other.

5)Finally, in order to check that members of the two treatment groups did not differ systematically from one another, Trip0T1G and Trip0T2G were compared, matching each subject in T1G with their partner in T2G.

For each of these five pairs of trip-sets, the following comparisons were made in order to test the effects of the independent variables.

(A) Trip time. Trip times were recorded in seconds. Due to equipment problems, times for two trips (Trip1-S22 and Trip2-S14) were inadvertently not recorded, and these trips were omitted from this part of the analysis. Comparisons (1)-(4) above were made using a one-tailed t-test for related samples, with members of the second of each pair of trip-sets expected to show shorter journey times; a two-tailed t-test was used for comparison (5).

(B) Planning times. Pre-trip planning times were recorded to the nearest minute, but otherwise analyzed in the same way as trip times, except that a two-tailed test was applied to comparison (1).

(C) The number of halts made en route during each trip was recorded: a "halt" involved pulling out of the stream of traffic and bringing the car to a standstill. Comparisons 1-4 were made using a one-tailed Wilcoxon rank sum test, with members of the second set of each pair expected to show fewer halts. Comparison (5) was made using a two-tailed Wilcoxon rank sum test.

(D) U-turns were analyzed identically. A U-turn was defined as a manoeuvre with the net effect and apparent intention of reversing direction and going back along the road being followed. This might be done by reversing in the road, going right round a roundabout to achieve a 180 degree turn, or going down a side-road and either reversing in the side-road or driving around a short loop in the network.

(E) The independent variables' effects on mood shift during trips were examined as follows. Before and after each trip, each subject checked one of four words ranged along a "negative/positive" scale (ANGRY, NERVOUS, RELAXED, HAPPY). For each trip, it was noted whether there was an improvement, a deterioration, or no change. Pairs of trip sets were then compared using the sign test: if the first member of a trip-pair showed an improvement while the other did not, or the first showed no change and the second showed a deterioration, this was counted as a "+" instance for the purposes of the sign test; if the two members of the trip-pair both showed an improvement, both showed deterioration, or both showed no change, this was counted as a "0" instance; otherwise, the trip-pair was counted as a "-" instance. For comparisons (1)-(4), the second trip-set was expected to show more of a positive mood shift (or less of a negative one) than the first. For comparison (5) no difference was expected.

(F) We measured the closeness of the routes subjects followed to the recommendations of the guidance system in two ways (both of which could be applied whether or not guidance was actually being given). The first was to calculate each route's similarity to the route which would be followed if guidance were always obeyed (the "G-route") using the procedure for any pair of routes described in appendix 3. These "G-route similarity" scores were then compared using a Wilcoxon rank sum test, one-tailed for comparisons (1)-(4) (with the second member of each pair expected to have a greater score), two-tailed for comparison (5).

(G) The second measure of a route's closeness to the recommendations of the guidance system (the "compliance score") was calculated as follows. Considering the whole of a given trip, a count was made of all points at which following either the subject's route, or the guidance system's recommendation (or both) involved a "continuity break". The term "continuity break" is precisely defined in appendix 3; roughly, it means making a turn, or crossing either a roundabout or a more major road than the one you are on. The proportion of these points at which the subject's route agrees with the guidance system's recommendation is the compliance score: perfect compliance would give a score of 1, complete refusal to comply a score of 0. The compliance score, unlike the route-similarity score, takes account of the subjects' choices when not on the G-route. However, if a subject strayed off the guidance network altogether, route-choices made subsequently would not affect the score until the subject's route returned to the guidance network. Compliance scores were compared using the same tests as for G-route similarity scores.

4.RESULTS OF HYPOTHESIS TESTING

Table 1 shows the results of the 35 (5*7) statistical tests applied.

First, note that none of the comparisons between trip-set pair (5) (Trip0T1G and Trip0T2G) gave significant results (this was as expected). In all one-tailed tests where differences were found, these were in the expected direction, whether significant or not. It should be noted that with among so many tests, one or two results with $P<.025$ might be expected by chance.

No significant results were obtained with regard to mood shift (measure E). For the two measures of closeness of the routes chosen to the G-route (F and G), significant differences in the expected direction were found for all trip-set pairs (1)-(4), the most significant ($p<.005$) being found for differences between T2G subjects' Trip0 and Trip2 routes, and between the T1G and T2G subjects on Trip2. These are two of the three comparisons that involve the presence or absence of guidance.

Guidance plus prior experience (comparison (4)), and prior experience alone (comparison (1)) were found to reduce trip times significantly. Comparisons (2) and (3), where the distinction between the two trip sets was the presence or absence of guidance, show differences in the expected direction but below the 5% level of significance. For planning times, trip-set pair (4) (T2G subjects on Trip0 and Trip2, showing the effects of guidance combined with prior experience) and trip-set pair (2) (Trip1: T1G versus T2G subjects, showing the effects of guidance on a novel trip) produced the expected significant differences in planning time. Trip-set pair (1) (T1G subjects on Trip0 and Trip2, indicating the effects of prior experience alone) also showed a significant effect. This result suggests that the effect of additional information in making planning easier outweighed any tendency for this extra information to encourage more detailed

Table 1: Results of Statistical Tests

	(1): Trip0T1G Trip2T1G	(2) Trip1T2G Trip1T1G	(3) Trip2T1G Trip2T2G	(4) Trip0T2G Trip2T2G	(5) Trip0T1G Trip0T2G
(A) Trip times (t-test)	t=3.13 7df **p<.01**	t=1.68 7df	t=0.36 8df	t=3.72 7df **p<.005**	t=1.08 8df 2-tailed
(B) Planning times (t-test)	t=2.79 8df **p<.025** 2-tailed	t=2.16 8df **p<.05**	t=1.09 8df	t=3.04 8df **p<.01**	t=1.36 8df 2-tailed
(C) Halts (rank sum test)	N=6, rank sum=1.5 **p<.05**	N=4, rank sum=2	N=4, rank sum=0	N=9, rank sum=0 **p<.005**	N=6, rank sum=10 2-tailed
(D) U-turns (rank sum test)	N=5, rank sum=0 **p<.05**	N=4, rank sum=0	N=2, rank sum=1	N=9, rank sum=0 **p<.005**	N=12, rank sum=12 2-tailed
(E) Mood shift (sign test)	N=1, x=0	N=2, x=1 **	N=2, x=1 **	N=7, x=2	N=7, x=2 2-tailed
(F) G-route similarity (rank sum test)	N=8, rank sum=3 **p<.025**	N=8, rank sum=6 **p<.05**	N=9, rank sum=0 **p<.005**	N=8, rank sum=0 **p<.005**	N=9, rank sum=11 2-tailed
(G) Compliance (rank sum test)	N=6, rank sum=0 **p<.025**	N=7, rank sum=2 **p<.025**	N=9, rank sum=1 **p<.005**	N=9, rank sum=0 **p<.005**	N=7, rank sum=14 2-tailed

All non-significant results except the two marked ** were nevertheless in the expected direction. These two results showed an even balance between the two conditions. All tests 1-tailed unless otherwise specified.

planning. Finally, counting the number of halts and U-turns made during the trip gave significant results only for comparisons (1) and (4).

The results confirmed the hypotheses tested so far as the route taken is concerned: both guidance, and prior experience, significantly affected the route followed. Prior experience also reduced trip time, planning time, and the number of halts and U-turns. Guidance may do the same, results on these measures being mostly in the expected direction but short of significance. The relationship between planning time and trip time was also investigated, but no convincing correlations were discovered.

5.QUALITATIVE OBSERVATIONS

This section is divided into four subsections. The first three deal with pre-trip planning, route-choice criteria and reactions to guidance, and error and error-recovery, while the fourth is a brief discussion of the processes of route-planning and route-following in more general terms. Maps 3 and 4, referred to throughout this section, show the networks used in Trip1, and Trip0/Trip2 respectively (most minor roads are omitted; some junctions are numbered for convenient reference).

5.1PRE-TRIP PLANNING

As noted in section 4, there were no clear correlations (positive or negative) between time spent on pre-trip planning, and journey time. Perhaps such a straightforward relationship was too much to hope for: the amount of planning it is useful to do may vary nonlinearly with both route-following skill and network knowledge. Nevertheless, despite the failure to find correlations between planning and journey times, it seemed worth comparing the actual products of planning (written, drawn and spoken) produced by the subjects with the longest and shortest journey times. For Trip0, for which all subjects were treated the same and for which there was the greatest range of journey times, the three shortest journey times were those of subjects S3, S7 and S22 (in that order), the three longest were for subjects S25, S13 and S1 (again, in that order). The sketches and/or notes produced by these subjects are reproduced as appendix 5. There is no clear distinction between them in terms of length or coherence of plan produced. None of the subjects made a clear error in planning the route, although the notes produced by S1 have an apparent gap between the two directions "Left Wood Lane" and "First Right Slip Road": between these two anyone attempting to follow this route must turn right and then left to get from Wood Lane onto the Ring Road. In fact, this subject missed a turning before this point, reached the Ring Road at a different junction, and then got thoroughly confused - but it is not obvious that the gap in the written plan was the reason for this. Tentatively, it can be concluded that differences in route-following ability are more important than those in route-planning skill in determining journey time.

Table 2 concerns the content of the spoken, written and sketched products of the subjects' planning. The first three rows below the headings show how many subjects produced anything in the way of sketches, notes, and spoken plans in each of the six groups of nine trips. Subsequent rows show how many of these subjects included particular aspects of the trip or environment in the products of their planning: the first figure in each cell gives the total who included a particular type of element in sketch, notes, *or* spoken planning, while the figure in parentheses shows how many of these included that type of element in either notes or sketches (i.e. in those planning products that remained available for consultation during the journey).

The row-identifiers in the leftmost column require some explanation. The three immediately below "spoken" identify different ways of referring to particular stretches of road - generally those which the subject is planning to travel along. Such a stretch of road may be identified by name (e.g. "Back Lane"), by number (e.g. "the A58"), or by some characteristic which distinguishes it from any other, in the context of what the subject has already said (e.g. "the main road"). The next five rows concern different ways of referring to nodes in the network. Sometimes, but surprisingly rarely, a subject referred simply to "the junction" or "the intersection", allowing context to disambiguate the reference. Similar references to crossroads were about as frequent, while those to roundabouts were far more common. (The "Armley gyratory" is a kind of super-roundabout situated at 3048 on Map

4.) Occasionally, references were made to other types of junction (e.g., to a "staggered junction"). Almost all the references made to bends or corners at points where there was no node concerned one particular point: the bend between nodes 1538 and 117 on Map 4. The next row-label, "District", identifies those points at which subjects referred to areas of

Table 2: Content of Products of Subjects' Planning

	Trip0T1G	Trip0T2G	Trip1T1G	Trip1T2G	Trip2T1G	Trip2T2G
Sketch	3	1	0	1	2	1
Notes	7	7	3	5	5	1
Spoken	8	9	5	9	7	4
Road Name	8(7)	9(6)	5(3)	9(6)	7(6)	3(2)
Road Number	3(3)	6(5)	2(2)	7(6)	6(6)	1(1)
Road Type	3(1)	3(0)	0(0)	3(0)	3(1)	0(0)
Junction/ Intersection	1(0)	0(0)	0(0)	0(0)	2(0)	1(0)
Roundabout	5(5)	8(8)	4(2)	8(5)	5(5)	2(1)
Armley gyratory	1(1)	0(0)	0(0)	0(0)	1(1)	0(0)
Crossroads	0(0)	3(2)	0(0)	1(1)	1(1)	1(1)
Junction Type	0(0)	0(0)	0(0)	1(0)	2(2)	1(0)
Bend/ Corner	4(4)	1(1)	1(1)	0(0)	2(2)	0(0)
District	3(0)	5(2)	2(1)	3(2)	2(0)	0(0)
Bridge	0(0)	1(0)	0(0)	0(0)	2(1)	0(0)
Cemetery	0(0)	1(1)	0(0)	0(0)	0(0)	0(0)
Church	1(1)	0(0)	0(0)	1(0)	0(0)	0(0)
Cricket Ground	0(0)	1(0)	0(0)	0(0)	0(0)	0(0)
Recreation Ground	0(0)	0(0)	1(1)	1(1)	1(1)	0(0)
School	0(0)	0(0)	0(0)	1(1)	0(0)	0(0)
Sewage Works	0(0)	0(0)	0(0)	1(0)	0(0)	0(0)
Sports Centre	0(0)	0(0)	1(1)	0(0)	0(0)	0(0)
Traffic Lights	0(0)	0(0)	0(0)	0(0)	1(0)	0(0)
Signs	0(0)	1(0)	0(0)	3(1)	0(0)	0(0)
Turn	6(5)	9(9)	5(3)	7(5)	7(6)	2(2)

Top/End	1(1)	1(0)	1(0)	1(0)	1(0)	0(0)
Compass	1(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Sequence	4(4)	4(4)	2(2)	5(3)	3(3)	0(0)

significant size they would travel through or towards (e.g. "Rodley", "central Leeds", "Dewsbury"). The next nine rows (down to and including "Traffic lights") should be self-explanatory. It is perhaps surprising that only one subject referred to traffic lights during planning, but they are not marked on the map the subjects used. "Signs" refers to occasions when a subject said they would be looking out for signs to some particular place.

The last four rows deal, not with observable elements of the environment as such, but with specifications of what the subject intended to do at particular points in the journey planned. "Turn" refers to occasions when the subject specified which direction was to be taken at a particular point (generally "left", "right", or "straight on" but occasionally something rather more complex such as "bear right"). "Top/end" refers to points at which the subject indicated that a road would be followed until the subject reached the end, or "top" - generally meaning a T-junction which the subject planned to approach along the stem. "Compass" means reference to one or more compass directions - surprisingly used only once, despite the ready availability of the compass directions from the map used. Finally, "Sequence" includes all references to "the first...", "the second..." etc., and to "the next...".

Looking at the first three rows of the table, we can see that across all six trip-sets, more subjects produced at least something (sometimes very little) in the way of a spoken plan than produced notes, and with a single exception, more produced notes than sketches. It should be noted that some of the sketches referred to were mere fragments accompanying a set of notes. Looking at the rest of the table, it is not surprising that more unguided subjects (Trip1T2G and Trip2T1G) produced spoken plans, notes or sketches than the corresponding guided subjects (Trip1T1G and Trip2T2G respectively), and most types of element were also referred to by fewer guided than unguided subjects. Across all trip sets, road names, road numbers, roundabouts and turn and sequence descriptions account for a very high proportion of the information contained in the products of planning. The prevalence of references to roundabouts may be a result of the large numbers of roundabouts in the network where the journeys were made. It is perhaps surprising that subjects did not make greater efforts to identify from the map buildings or places (such as schools, bridges or cricket grounds) that would tend to be readily identifiable cues to where a turn should be made during the journey; the heavy reliance on road names and numbers, combined with the rather poor quality of street-name signing in the area, may partly account for the high error-rates found.

Some odds and ends not included in the table are worth noting. Several subjects referred in one way or another to the overall shape of the route, or a part of the route, that they were intending to take. On Trip0, S6 said that one possible route (not the one he eventually took) would "cut the corner off", while S14 remarked early in his planning that he was looking at "prominent roads in the general direction" of the destination. In planning Trip2, S15 said "I remember taking this great long V-shape" in making Trip0. Going back to Trip0, S24 referred to the possibility of "heavy traffic and stuff" on one possible route - the only reference to likely congestion in any subject's planning.

The way in which subjects' sketched or written plans segmented their planned routes usually corresponded closely, and in some cases perfectly, with the division of routes into stretches separated by "continuity-breaks" explained in appendix 1 - providing some support for this approach to route-description. This can be seen in some of the examples included as appendix 5, particularly the notes and sketch S3 made for Trip0: a roundabout on the Ring Road is not mentioned (the subject intended going straight on), but otherwise the correspondence is complete.

The planning process was not always a straightforward, start-to-finish affair. A number of subjects considered more than one alternative route and then decided between them. This, interestingly, appeared most clearly on Trip1, where S1, S6, S22 and S24 all made an explicit choice between two alternatives. These were whether to go via 1586-1670-1678-1682 or 1586-1670-1675-1682 (see Map 3) in the cases of S1 and S22; whether to go via 1586-1670-1675-1682 or 1586-547-1682 in the case of S6; and whether to go via 1586-547-1682 or 1586-1670-(remainder unspecified) in the case of S24. Possibly, the greater simplicity of the Trip1 problem relative to the Trip0/Trip2 problem allowed subjects the luxury of weighing the benefits of global alternatives against each other.

A number of subjects "stepped back" from the process of working out a route to comment on the likely difficulty of the task or some particular part of it, the possibility of getting lost or of stopping on the way to continue planning, or their own strategies. However, no obvious pattern emerges from these comments.

5.2ROUTE-CHOICE CRITERIA AND DIVERGENCES FROM GUIDANCE

Trip1 presented a relatively simple wayfinding problem to subjects (see Map 3). Subjects' responses (whether or not they were receiving guidance) can conveniently be analyzed in terms of divergences (deliberate or accidental) from the recommendations of the guidance system. Deliberate divergences are dealt with in this subsection, accidental ones (errors) in the next.

There appear to have been just two points at which subjects (with or without guidance), deliberately diverged from the route the guidance system recommended (the G-route). The first of these involved turning left at the roundabout (1586) reached almost immediately after setting out; this was taken by four unguided subjects, but just one guided one. The second was to turn left at junction (1570), instead of carrying straight on to (1575). This, interestingly, was taken by three guided subjects, but no unguided ones.

To turn left at (1586), a guided subject would have had to go against the explicit advice of the guidance system, which tells the subject to go "Straight on at roundabout". Turning left at (1570), on the other hand, involves making a turn when the guidance system is silent. Despite being told that in this case, the system's advice was to continue following the current road, subjects may well have found it easier to ignore guidance which was implicit rather than explicit.

Of the two alternatives to the G-route, going left at (1586) may indicate a route-choice criterion of keeping to the main roads (both other routes involve what look like substantially less major roads on the map). Going left at (1570) suggests the use of a "shortest route" or "crowfly" criterion. The subjects' responses to a question in the post-trip questionnaire about their route-selection criteria (those who admitted to planning their route were asked to indicate whether they chose their route as the shortest, quickest, most straightforward, safest, or on some other grounds) did not match up well with their choice between the three routes. Of the nine unguided subjects, seven ticked "most straightforward", of whom three chose the G-route, three the "major road" route and one the "crowfly" route. The other two subjects indicated that they had chosen the shortest route: one took the G-route, the other the "main road" route - which is the longest of the three! It is notable that no subject indicated choosing what was considered the quickest (or safest) route, perhaps because they were aware of lacking sufficient information on which to base such judgements.

A considerably simplified version of the network connecting the origin and destination used in Trip0 and Trip2 is shown as Map 4. Here, there are three different experimental conditions to consider: Trip0, made by all subjects without either guidance or prior experience; and Trip2, made either with or without guidance.

Indicated on Map 4 are the initial parts of the 36 trips (two per subject) made on this network. Consider 5 possible ways in which the journey can begin: 1539-1538-117, 1539-115-116, 1539-1433, 1430-1433 and 1430-3048 (covering two slightly different routes). The first two of these look like the result of applying a "crowfly" route-choice criterion, the other three, a "main road" or "most straightforward route" criterion. Questionnaire results and subjects' comments again indicate that "straightforward" may be ambiguous, with some subjects interpreting it as "direct", others as "easy to follow", as intended. Those subjects who went to 1433 via 1430 may have done so because the car reached O_A via 1430 and 1546 before the experimental trip began, so subjects were somewhat familiar with this section of the route. Alternatively, the subjects may have been avoiding making a right turn, although none mentioned this consideration while planning.

If we compare Trip0 with Trip2, it can be seen that six of the T2G subjects (numbers ringed on Map 4) switch from a "main road" start to one of the "shortest route" starts, in accordance with the guidance they received on Trip2. However, there is also some sign of movement toward "shortest route" starts among T1G subjects, who received no Trip2 guidance: five out of nine take such a route in Trip2, compared to only three in Trip0.

Subjects' comments during planning and driving shed some light on this: the basis on which a route is chosen is itself a matter of judgement, and can vary from trip to trip according to circumstances. One subject, who followed a "main road" route, commented that in peak hour, he might have studied the map longer and taken minor routes. Another noted that since the area was unfamiliar and congestion was unlikely, he would stick to the main routes. On Trip2, most unguided subjects followed a route close to their Trip0 route (six out of nine selecting the same one of the five starts as in Trip0), but the changes tended to be in the direction of shorter routes making more use of relatively minor roads.

Subjects almost always complied with guidance on Trip2 when available: there were only two deliberate divergences from the recommendations. We can also ask where *unguided* subjects diverged from what the system *would have* recommended. The cases where guidance would have recommended a continuity-breaking choice at a junction total 85. In 71 of these cases, guidance would have recommended the exit that points most directly toward the final destination; unguided subjects took this exit on 61 of these occasions, deliberately took another on nine, and accidentally took another on one. Of the 14 cases where some exit other than that recommended by guidance points at least equally directly to the destination, unguided subjects took the recommended exit in eight cases, deliberately took another in five, and took another in error in one. These figures suggest that in the absence of guidance, the "crowfly" direction could be a useful predictor of exit-choice, reinforcing one of the main findings of our work with the IGOR route choice simulator (Bonsall and Joint, 1991).

5.3ERROR AND ERROR-RECOVERY

The routes actually taken by drivers in this study, particularly in the case of Trip0, depended not just on subjects' advance plans, but also on the errors they made. Exit-choices made were judged to be errors in the light of the subject's spoken or written plans before the event, and comments and behaviour such as halts to replan and U-turns after it. In this subsection as in the last, the comparatively simple Trip1 will be dealt with first.

Of the 12 apparent errors made on Trip1, all but one can be classified as "overshoot" errors, in which the subject is proceeding along one road, looking for a particular turn off it, and misses the turn. (These errors are quite easy to diagnose, because the subject typically realises fairly soon that the desired turning has been missed, and makes this clear in words and actions.) Eight of these twelve errors, including the only two made by guided subjects, were at the final junction (201), where a right turn follows immediately the subject comes off a roundabout. The one non-overshoot error, in which an unguided subject went right at (1586), is not readily explicable.

Only two of the 18 subjects made no errors on Trip0. Of the 40 identified Trip0 errors, 25 were simple overshoots. The poor quality of road-sign provision certainly contributed considerably to this number. Perhaps the most interesting errors appeared to be at least partly due to misinterpretations of the map. Three out of the six subjects who went through (103) mistakenly thought they had reached (1482) and turned right: on the map used by the subjects, the staggered junction at (103) and (104) is visible only as a tiny kink in the road (because street maps exaggerate road-widths, following the road from (1472) to (1482) appears to involve no continuity breaks unless you look very closely). At (1472), four out of seven subjects took the first exit (toward (1501)) in mistake for the second (toward (103)). This may have been due partly to map interpretation (the road taken looks minor on the map, but appears quite major on the ground), and partly to a misleading depiction of the roundabout on a sign encountered when approaching it from (1475). On this sign, the second exit appears at the angle actually taken by the first exit.

Several subjects became confused after errors at these points, some making further errors as a result of becoming wrongly oriented - thinking they had followed their plans when they had not. Yet quite simple changes to maps and road signs to make junction structure clearer could have enabled them to avoid these errors.

We can distinguish three types of error in the process of planning and following a route. The first is the *planning error*, in which the plan the subject makes cannot be carried out as intended, because it is incomplete at some point, or relies on a manoeuvre which is not in fact possible (e.g., planning to go down a road which is actually one-way in the opposite direction). The second is the *orientation error*, in which the subject, while attempting to follow the plan made, comes to believe he or she is somewhere other than is actually the case. The third is the *route error*, in which the subject actually deviates from the intended route.

Parenthetically, it may be wondered whether route errors can be made without a preliminary orientation error: after all, unless you are mistaken about where you are (at least in the sense of mistaking one exit from an intersection or roundabout for another), why should you take a wrong turning? There are no examples among the trips made in this experiment, but it can be done: if you are very used to taking a certain exit from a junction in making a frequently-repeated journey, you may absent-mindedly do so even if your destination on this occasion was different, and required a different choice.

Error-recovery can be divided into four stages: discovery, diagnosis, replanning, and resumption of the journey. Further errors can take place at any of the last three stages, and the "discovery" itself may *be* an orientation error: such an error can lead the subject to believe that a planning or route error has been made when this is not in fact the case. The remainder of this subsection illustrates the types of error and processes of error-recovery with examples from Trip0.

There are few clear examples of planning errors among the plans made for Trip0 (and none for Trip1 or Trip2 plans). S1's plan, as already noted, appears to have a gap in the middle, and S17's is very vague:

"Right, I'll probably head back along Gelderd Road, to the Ring Road, and then try and get along up through Wortley and Farnley."

Both these subjects made route errors, but S1, as noted, made his first before reaching the gap in his plan, and S17 halted to continue planning, came up with a reasonable continuation, and then immediately made an orientation error (believing himself to be one junction further along the road he was following than was the case) followed by a route error - turning off at this junction.

S5's plan included an impossible switch from the Ring Road (the prominent road through (1433) and (1475)) to the eastern part of the Stanningley Bypass (which runs from (1523) to (3048). S5 realised this just after passing (1523), halted, and planned a new route.

Cases where planning error did apparently lead to route error (via an intermediate orientation error) include those occurrences already mentioned, where the staggered junction at (103) and (104) was overlooked during planning, and the subjects went right at (103) in the belief that it was (1482).

S6 and S7 both made orientation errors which led them to the false belief that they had made route errors. In S6's case, this was shortly after the roundabout (1472), where a number of subjects did in fact make an error, taking the first exit instead of the second. S6's belief that he had made an error may similarly have stemmed from the misleading representation of the roundabout (mentioned above) on a sign encountered when approaching it. S7's error, which was quickly corrected, arose from the fact that, like several other subjects, he misidentified the unusual pair of junctions at (101) and (1539) as a roundabout on the map, and was initially mystified on reaching them.

The four-stage process of error-recovery - and some of the ways it can go wrong, generating further errors - can be illustrated from the middle part of S13's Trip0. S13, like some other subjects, made an orientation error and a consequent route error at (103) (turning into Broad Lane), thinking it was actually (1482). Not finding the left turn into Pollard Lane (1478) he expected, he turned into Wood Lane at (126) and halted in order to check where he was, not being certain at that point whether he had made a route error or not. He looked around to find a street name, commenting on their paucity, and eventually found Wood Lane on the map - this constituted the definite discovery of an error, and was immediately followed by a diagnosis:

"So the right I took thinking it was Leeds and Bradford Road wasn't in fact Leeds and Bradford Road."

This in turn was followed by the replanning process. Initially, S13 intended to do a U-turn in Wood Lane, but then realised he could follow it round to its other end, as this would take him back to Broad Lane, and then turn right at (104) and proceed as originally planned. It is notable that S13 did not notice either of two short cuts: the one via (127) and (129), or the one via a right turn off Broad Lane at (109). This is a fairly common phenomenon: after the discovery and diagnosis of a route error, the subject looks for the best way *back to the point at which the error was made*, rather than the best route from the current location to the final destination. Sometimes, of course, there is no short cut such as this example provides, and sometimes the subject may save on replanning time enough to compensate for the extra travelling time, but in this case it seems clear the decision was sub-optimal. In fact, S13 made a planning error during replanning, identifying (104) as "the end of Broad Lane" (which it is not), and subsequently going past it and misidentifying (110) as (104), leading to considerable further confusion!

5.4DISCUSSION

The work reported in this paper illustrates the complexity of drivers' route-choice and route-following strategies. It shows that factors including the directness of possible routes, their perceived complexity, and familiarity all affect route choice, but to different extents for different individuals and under different circumstances. Error is shown to be an important factor in determining the route actually followed in novel and relatively difficult problems (confirming the results of Lunn 1978 and King 1986), and it is argued that deficiencies in street signs and difficulties in map interpretation contribute considerably to the error-rate.

In section 1.2. it was suggested that the effects of different levels of familiarity, and of the availability of guidance, on route-planning and route-following could be approached by considering the range of information sources available to a traveller, and their judgement of the relevance and reliability of those sources. In these terms, pre-trip planning can be regarded as the creation of new information sources - internal or external - from old. (If the traveller is sufficiently familiar with the relevant parts of the network, or knows that adequate instructions will be available from a passenger or guidance system, planning is unnecessary. If insufficient information is available from existing sources, it may not be possible.)

The main old source for Trip0 and Trip1 was the map subjects were supplied with, supplemented in the case of Trip2 by the memory of Trip0 itself. The new source or sources created must, if the planning is to be effective, take the form of a *sequence of instructions*, detailed enough to allow the traveller to keep track of his or her current location during the journey, and to make the correct decisions at network nodes. A map, by contrast, contains information in a non-instructional, non-sequential form: information that can potentially be of use in a myriad different journeys, but which does not in itself tell the traveller which way to go to reach any particular destination. Similarly, the memory of a previous trip, particularly if it involved a considerable amount of backtracking and error-recovery, may need a lot of processing in order to be useful.

It was noted in 5.2 that no subjects indicated that they had chosen a route on the grounds of speed or safety - rather, minimising distance and maximising "straightforwardness" were the main criteria adopted. A conventional scale map, of course, encourages the use of a "crowfly" or "minimum distance" criterion, because the direct line between origin and destination can be "read off" very easily. One subject reported that he was looking at major roads in the "general direction" of the destination. A scale map makes it easy to do this, or to look for major obstacles between origin and destination and then for ways through or around them. A particular source of information, then, will tend to encourage some criteria and discourage others. This should be borne in mind in designing route-following aids of any type. So should subjects' apparent willingness to go against the "advice" of the guidance system when this is expressed in the form of a default choice, such as going straight ahead when not told to do anything else.

A particular type of information source may also encourage or allow particular types of error. As was described in 5.3, one particular feature of street-maps, the exaggeration of the width of roads, appears to have played a major part in generating errors and confusion by leading to a misleading representation of local road-layouts. Misleading representations of local road-layouts may also occur in other ways. For example, what appears to be road "A" branching off road "B", or a symmetrical fork on a scale map may appear as road "B" branching off road "A" on the ground - indeed such a case occurs at (1477) on Map 4, and did cause problems for one subject. It is not clear that map-makers give sufficient attention to this type of problem. It would not be difficult to devise a convention for showing the continuity-structure of junctions (which transitions from entry to exit appear to be "following the road" on the ground and which do not) in doubtful cases. Currently, many street-maps do not even indicate the existence of one-way systems.

6.ASSESSMENT OF THE EXPERIMENTAL TECHNIQUE

As with all experimental techniques, the type of mock-up study of route guidance reported here has both advantages and drawbacks. Some of the most significant "pros" and "cons" are listed below.

Pro:

1)Real networks and driving tasks are used. Problem-solving processes take place at their normal pace, while simulator techniques generally speed up subjects' trips and often omit sections of the journey altogether.

2)Large amounts and varied types of information can be collected during a single study.

3)The type of advice and/or information made available, and the form of presentation, are under a high degree of experimental control.

Con:

1)The expense per subject is high relative to simulator techniques.

2)There are limitations on experimental control - for example, there is no control of the level of congestion encountered.

3)There are some safety and ethical problems, as in any experimental technique which encourages subjects to undertake such a dangerous task as driving on public highways.

4)Subjects are likely to be few and of a limited range of types (mostly people who are not employed full-time) because of the demands the technique makes on their time.

5)Subjects must be deceived about the source of the guidance they are getting. Deception should always be avoided if possible, for both ethical and practical reasons.

From the excess of "cons" over "pros" it might be thought that the technique is not to be recommended. However, the three "pros" are of considerable weight, and the balance will depend upon the experimenter's purposes and the available alternatives.

Mock-up studies should be useful in suggesting a broad range of insights into drivers' behaviour and problem-solving processes, and also in testing specific hypotheses about the *direction* in which a specific change in the information available to the driver will alter performance. However, the technique probably imposes too high a cost per subject to permit testing of enough subjects to calibrate detailed models of drivers' responses.

7.FUTURE POSSIBILITIES

7.1INTRODUCTION

In this study, the mock-up technique was used with a guidance system which was *admitted* to be "static" (based on historic data), while many proposed real-world guidance systems are "dynamic", using real-time traffic information. Dynamic systems are central to our research interests. The usefulness of static guidance systems is likely to be limited: drivers who are familiar with an area are unlikely to make use of a guidance system unless it promises them the advantage of routes based on current rather than average traffic conditions, as they are likely to have found for themselves routes that work well under average conditions. We therefore intend implementing a "pseudo-dynamic" mock-up, which gives subjects the impression that real-time traffic information is being used, for use in a future study. This study will parallel parts of a study to be carried out using the new route choice simulator VLADIMIR, currently under development as a successor to IGOR.

The guidance given in the present study was the best that we could contrive. One of the major advantages of experiments using mock-up guidance systems, however, is the ability deliberately to give subjects sub-optimal advice - something which the developers of functioning guidance systems might be reluctant to allow. In the proposed study described below, we intend to use the mock-up approach to test the effects on compliance (both immediate and delayed) of different qualities of guidance.

The rest of this subsection sets out the requirements for a successful "pseudo-dynamic" mock-up guidance system, and outlines a proposed experiment.

7.2REQUIREMENTS FOR A PSEUDO-DYNAMIC GUIDANCE SYSTEM MOCK-UP

To produce useful results, a mock-up of a dynamic guidance system must be convincing: the subjects must believe they are indeed receiving advice from an experimental route guidance system with access to information about current traffic conditions. Experience with a mock-up of a static system suggests that subjects are inclined to accept what they are told by the experimenter, but the more realistic the appearance of the guidance equipment, and the better the story that accompanies it, the less likely it is that subjects will guess at the deception.

So far as guidance equipment is concerned, it is essential that the car appear capable of receiving radio information from a traffic information centre. If possible, the "guidance computer" should appear to be at least semi-permanently installed. We will need to tell subjects that the car is linked to a traffic information/control centre able to gather information from static cameras, human observers, and/or vehicles in the experimental network.

The main problem with mock-up experiments using a "pseudo-dynamic" guidance system (one presented to the subjects as dynamic, but in fact static) is that we cannot control levels of congestion. Experiments will have to be run at times where congestion may cause significant delay if they are to be credible as tests of what is purported to be a dynamic guidance system. Because of this, our control over the quality of guidance given will also be incomplete: while we can deliberately reduce the quality of guidance, we cannot avoid the possibility that day-to-day variation in traffic levels, or specific incidents, will "sabotage" the best advice we can produce, or even make what is supposed to be poor-quality advice better than intended.

7.3OUTLINE OF A PROPOSED EXPERIMENT

The proposed experiment will aim to show that the quality of guidance provided by a guidance system influences current and future compliance, as suggested by results of IGOR experiments. Compliance will be measured in both of the ways developed for the experiment reported in this paper (see section 3.2).

As noted above, we intend to use the mock-up technique as a check on the validity of results derived from the VLADIMIR route choice simulator. One of the main advantages of VLADIMIR over IGOR will be its ability to represent real road networks, in place of IGOR's entirely hypothetical network, using a combination of computer-generated graphics and photographs of points in the real network. Since the first real network to be encoded onto VLADIMIR will cover the area including Leeds and Bradford Airport and the University of Leeds, we intend that the mock-up study will take place in this area.

The details of the experimental design suggested here are put forward for further discussion.

7.3.1Method

Phase 1: Recruitment and initial data gathering.
This will closely resemble the initial phase of the experiment reported in this paper, and will be done on an earlier day than the remaining phases. Potential subjects will be told in general terms that the experiment concerns route-choice and automatic guidance systems, but given no more detail than this. They will be asked to fill in questionnaires including questions about their driving experience, and to show on maps which parts of Leeds they are familiar with. It is intended to

recruit two groups of subjects, one familiar and the other unfamiliar with the experimental area - the area between the University, and Leeds and Bradford airport.

Phase 2: First trip.
Phases 2-4 will be done in a single session for each subject, taking perhaps 2 hours. Each set of subjects will be subdivided into two treatment groups (or possibly more, but two will be assumed here). The two groups will be given different qualities of guidance ("better" and "worse" or B and W). Trips will be video recorded, preliminary planning audio recorded.

The subjects will be told they will be asked to make a trip, and given a map, paper and pen to plan a route if they wish. When they have finished, however, they will be told that advice will be available from a guidance system which has access to information about network layout and current traffic conditions, and asked to follow this advice. (There are two main points to asking subjects to plan their own route first: to make it easier for them to assess the quality of the guidance received, and to get a measure of how far their planned routes are similar to the guidance route.)

There are two advantages to instructing the subjects to follow guidance on their first trip. First, this ensures that all subjects within a treatment group will follow the same route and receive the same guidance messages, enhancing the size of treatment differences between groups relative to those within groups. Second, following the guidance system's preferred route for a complete journey should maximise subjects' ability to judge the quality of the advice they are getting - particularly for those familiar with the network. The procedure might seem artificial, but in fact a useful way for a potential buyer or hirer to test a guidance system offered for sale or hire would be to see how well it does in areas the potential customer knows well.

The guidance given to subjects being given the best advice we can provide will probably be worked out on the basis of trial runs rather than based on a SATURN model using data about average traffic conditions for the time of day, as in the experiment reported above, since there is currently no SATURN model of the relevant area. Advice of lower quality will be generated by deliberately degrading this best advice, as has been done in IGOR experiments.

After the trip (and after trips 2 and 3) subjects will fill in a questionnaire concentrating on their assessment of the guidance system.

Phase 3: Second trip.
On the second and third trips, the subjects will all be free to take the guidance system's advice or not as they prefer, junction by junction. These trips will be in the same general area as the first trip, but the exact relationships between the three has not yet been decided. One possibility is to make the second trip a reprise of the first, and the third trip the inverse of the first two. As for the first trip, subjects will be given a chance to plan their own route in advance, using a map.

For the second trip, each treatment group from trip 1 will be further divided into two subgroups, so that one of the subgroups receives better and one worse advice during trip 2. There will thus be four treatment groups in all for each of the two sets of subjects (familiar and unfamiliar), group BB (better advice on the first and second trips), BW, WB, and WW.

Phase 4: Third trip.

On the third trip, all subjects will be given the same quality of guidance, making it possible to compare the effects of four advice-quality histories (BB, BW, WB and WW) on level of compliance. The procedure will be the same as for the second trip from the subject's point of view.

7.3.2Analysis

The subjects' behaviour can be analyzed in two ways: comparisons between treatment groups to test specific hypotheses about the effects of treatment differences and differences in initial network familiarity, and within-group regression analyses. The latter will in effect look for the effects of uncontrolled variations in the traffic conditions, and so in the apparent quality of guidance.

Trip 2.
The effect of current-journey advice quality on compliance can be tested by comparing the compliance levels of treatment group BB with BW, and group WB with WW. The first of each pair is expected to show higher compliance, on the hypothesis that subjects given the "better" advice will judge the advice they are given more favourably than will those given the "worse" advice. Effects of different qualities of advice on trip times will also be tested for (better-quality guidance is expected to reduce mean trip time). The effect of past-journey advice quality can be tested by comparing BB with WB, and BW with WW, again with the first of each pair expected to show greater compliance, on the hypothesis that perceptions of past journey guidance system performance will affect compliance on the current journey. Across all treatment groups, unfamiliar subjects are expected to show greater compliance than familiar ones. Differences between treatment groups are expected to be greater for familiar than unfamiliar subjects, as the former will be better able to judge advice quality.

The association of trip 2 compliance scores with subjects' assessment of the guidance they were given on trip 1 can be tested by regression analyses applied to the subjects in each treatment group separately. The association of trip 2 compliance scores with trip 1 journey times can be examined in the same way. More favourable assessments of the guidance system, and shorter journey times, are both expected to be associated with higher levels of compliance.

Trip 3.
Considering the six possible pairwise comparisons between treatment groups, BB can be expected to give a higher level of compliance on trip 3 than any other treatment group and WW lower than any other group; what should be expected of the comparison BW/WB is less clear. It is hypothesized that the first journey (a forced-compliance journey in a familiar area) will have more influence on the subjects' assessment of the advice system than the second (a voluntary-compliance journey in an unfamiliar area), so that BW will give a higher compliance level than WB. However, differences between trip areas might mask such an effect. An ANOVA is worth considering as an alternative to pairwise comparisons.

As with trip 2, within-group regression analysis can be carried out, looking at the association of trip 1 and trip 2 measurements (journey times and post-trip assessments of the guidance system) with trip 3 compliance scores. Trip 2 post-trip assessments should clearly have a stronger association with high compliance on trip 3 than trip 1 assessments.

Junction-by-junction logit analysis.
In addition to the trip-by-trip analysis outlined above, it should be possible to apply a logit analysis to the subjects' exit-choices on a junction-by-junction basis, as with the analysis of IGOR exit-choices.

7.3.3 Possible modifications

It would be possible to extend the experiment outlined to more than 2 levels of advice quality, or to more than 3 trips, although the first of these might require too many subjects, the second too much time from each subject. It would also be possible to modify the experiment so that trip 1 was, like the other trips, a voluntary-compliance trip in an unfamiliar area. In this case, the BW/WB comparison of trip 2 compliance is still more difficult to predict, but we would still hypothesize that BW would give higher compliance levels than WB: the first journey would be expected to have a greater effect on the subject's assessment of guidance quality than any subsequent trip simply because the evidence it provides is "undiluted" by that of any other journey.

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APPENDIX 1: GUIDANCE MESSAGES USED

NEXT LEFT
SECOND LEFT
FORK LEFT
LEFT ONTO SLIP ROAD
LEFT AT JUNCTION
BE READY TO TURN LEFT
FOLLOW ROAD LEFT
TURN LEFT THEN RIGHT

NEXT RIGHT
SECOND RIGHT
FORK RIGHT
RIGHT ONTO SLIP ROAD
RIGHT AT JUNCTION
BE READY TO TURN RIGHT
FOLLOW ROAD RIGHT
TURN RIGHT THEN LEFT

FIRST EXIT AT ROUNDABOUT
SECOND EXIT AT ROUNDABOUT
THIRD EXIT AT ROUNDABOUT
FOURTH EXIT AT ROUNDABOUT
FIFTH EXIT AT ROUNDABOUT

LEFT AT ROUNDABOUT
STRAIGHT ON AT ROUNDABOUT
RIGHT AT ROUNDABOUT
BACK THIS WAY AT ROUNDABOUT

BACK THIS WAY AT JUNCTION

STOP HERE

OFF GUIDANCE NETWORK
BACK ON GUIDANCE NETWORK

APPENDIX 2: QUESTIONNAIRES AND EXPLANATIONS FOR SUBJECTS

Three questionnaires are included: the questionnaire used during the recruitment phase (phase 0) (page 27), and the two post-trip questionnaire - that used after unguided trips (pages 28-30), and that used after guided trips (pages 31-33). Three written explanations for subjects are also included: one to be used before Trip0 (page 34), one to be used before whichever of Trip1 and Trip2 is unguided (page 41), the third to be used before whichever of Trip1 and Trip2 is guided (pages 36-37). The numbers at the bottom of the pages were not in the original, and are added here for convenience.

APPENDIX 3: THE CALCULATION OF ROUTE-SIMILARITY SCORES

Fig.1. Route similarity

There are several possible approaches to measuring the similarity of the route chosen to that favoured by the guidance system. We wanted a criterion which would measure how similar the sequence of choices made by the driver was to that proposed by the guidance system (or for that matter, by another driver, or the same driver on another occasion). Criteria based on the proportion of overlap between the routes in terms of the length or number of shared links were rejected because of cases like the (admittedly artificial) Fig.1. Here, all 3 routes from the left to the right of the network (A, B, G) are identical in length and in number of links (27). A and G share a greater number of links (18) than B and G (14), and the total length of these shared links is greater than for B and G. Yet B and G only make contrary decisions at one point (point 1). A and G differ at points (2), (3) and (4). The measure of route-similarity adopted depends upon the notion of a "continuity break" in a route followed by a driver. A continuity break occurs when either:

1)The driver does a U-turn, whether in the middle of a link, or at a dead end.

or

2)The driver passes through a road-junction at which there is a choice of possible exits (not counting the link used to enter the junction) and the exit taken by the driver means that *either* the driver should indicate left or right before taking the chosen exit, *or* conflicting traffic always has at least equal priority.

Condition (2) may look complicated, but is straightforward to apply under UK traffic laws. At a roundabout, there is always a continuity break, because the driver should always signal left when leaving the roundabout. At traffic lights, there will be a continuity break only if the driver turns left or right; when going straight on there will be no continuity break because there is a time (when the lights are green in the driver's favour) when conflicting traffic does *not* have at least equal priority. A driver on a major road crossing over a minor one does not go through a continuity break, while a driver on the minor road does. The continuity break similarity score for any two routes between a given origin and destination is calculated by counting the continuity breaks which the two routes share (both routes must enter and leave a node by the same links for it to count as a shared continuity break), multiplying this number by 2, and then dividing by the sum of continuity breaks in the two routes together. Halting at the end of the journey is counted as a continuity break, while starting off is not. This procedure gives a score (s) of 1 if the routes are identical, of 0 if they are completely disjoint, and of $0<s<1$ in cases of partial overlap.

APPENDIX 4: EQUIPMENT USED AND COSTS

Equipment

Small saloon car. (N.B. the model used had a sun-roof - something to be avoided in future as it made the installation of the camcorder more difficult.)

Camcorder (Sony)

Camcorder attachment system (pole, clamp, lead to cigarette lighter), purpose-built.

Tape recorder.

Speech synthesizer: Lightwriter SL30 manufactured by Toby Churchill Ltd.

Maps of Leeds for subject reference, plus one for subjects to mark the areas known to them (A-Z).

Questionnaires.

Map used to tell experimenter which keys to press when on the Lightwriter.

Pens, paper, clipboards.

Breakdown of costs of experiment

Labour: £10,500 (7 months work from research officer 1A, including salary and additional costs.

Car hire: £472.

Payment of subjects: £270.

Lightwriter hire: £49 plus £12 carriage.

Miscellaneous (maps, paper and pens, computer time, printing costs): approximately £50.

Other items used (camcorder, camcorder attachment system, tape recorder) generated no additional costs, as they were already available in the department.

Total: approximately £11,500.

APPENDIX 5: EXAMPLES OF SUBJECTS' NOTES AND SKETCHES

The notes (and sketches where applicable) included were made before Trip0 by the subjects with the three longest and three shortest subsequent trip times. They are ordered longest trip-time first (i.e. the longest (S25), second longest (S13), third longest (S1), third shortest (S22), second shortest (S7), shortest(S3)). Page numbers and identifying captions in typescript have been added to photocopies of the original notes and sketches.

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