Design for Smart Driving: A Tale of Two Interfaces

Mark S. Young[1], Stewart A. Birrell[1], and Neville A. Stanton[2]

[1] School of Engineering and Design, Brunel University, Uxbridge, Middlesex UB8 3PH, UK
[2] Transportation Research Group, University of Southampton, Highfield, Southampton, Hampshire SO17 1BJ, UK
{m.young,stewart.birrell}@brunel.ac.uk, n.stanton@soton.ac.uk

Abstract. The environmental and financial costs of road transport are a key issue for governments, car manufacturers and consumers. Alongside these issues remain longstanding concerns about road safety. The 'Foot-LITE' project is aimed at designing a 'smart' driving advisor to improve safe and eco-driving behaviours. This paper presents part of the human-centred design process to devise an in-car human-machine interface which will facilitate the desired behaviours while avoiding negative consequences of distraction. Two rapid prototyping studies are presented, and the results of feedback from potential users as well as subject matter experts are discussed with respect to implications for the future interface design.

1 Introduction

Over the past decade the environmental and economic costs of road transport has become a key issue for government, car manufacturers and consumers [10]. Meanwhile, road safety remains a key issue alongside these other concerns (e.g., [8]). One way in which the costs of driving can be reduced is by adopting 'smart' behaviours, which include a combination of both fuel efficient and safe driving styles.

'Foot-LITE' is a UK project, consisting of a consortium of five commercial companies, four governmental/charity organisations, and three universities, aimed at developing a system to encourage 'smart' driving behaviours. This would be achieved by providing pertinent advice on driving style, enabling drivers to adapt their behaviour and to make informed decisions about the trade-offs between eco- and safe driving. The work presented here is part of a package focused on the ergonomics of the system, with particular emphasis on the in-vehicle human machine interface (HMI), which will present information to the user while they are driving. In this paper, we explain the human-centred design development process for two candidate HMI concepts for Foot-LITE, before going on to describe two rapid prototyping studies aimed at enhancing and evaluating these concepts.

1.1 Design Development

In order to facilitate the design process, a Cognitive Work Analysis (CWA; [9]) was previously conducted for the Foot-LITE project [1]. Based on the output of this CWA,

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2009, LNAI 5639, pp. 477–485, 2009.

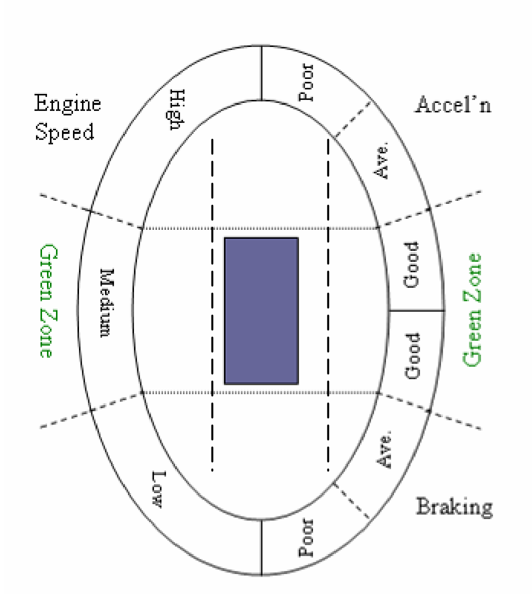

Fig. 1. Prototype EID interface

two concept HMIs were generated for the present study, one drawing on principles of Ecological Interface Design (EID; cf. [3]), while the other represents a more conventional dashboard (DB) layout based on traditional best practice in interface design.

Specifically relevant to the Foot-LITE project, EID offers to dynamically reflect the driving environment and integrate complex information onto a single, direct perception display. Figure 1 shows an early iteration of the EID interface developed at Brunel University for the Foot-LITE project[1]. The principal aspects of the interface are based on Gibson and Crooks [4] notion of the 'field of safe travel', which was noted as '…a spatial field but it is not fixed in physical space. The car is moving and the field moves with the car through space.' (p. 456).

As an alternative to the EID concept, a more conventional dashboard-type HMI (DB) has also been developed according to best practice in the human factors literature. Based on a vehicle instrument panel layout, the DB interface consists of bar charts, warning icons, pop-ups and textual information (see figure 2). The basic principles of the design are that Smart driving information is grouped (as with the EID), with the eco-driving parameters all being presented in the left hand circle, while safety-related information is shown in the circle on the right. The main centre circle has a smart driving meter situated at its crest, with additional driving related information or predefined Smart driving tips presented underneath. The DB design is intended to offer familiarity to drivers, being akin to standard instrument panels available in most vehicles.

[1] Due to commercial sensitivities, we are unable to publish any more recent or detailed versions of the interfaces.

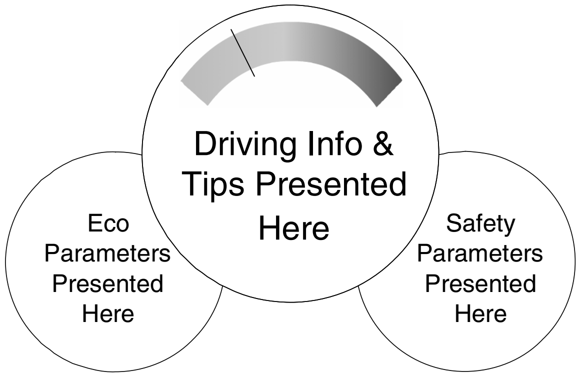

Fig. 2. Prototype DB interface

1.2 The Rapid Prototyping Study

In keeping with a human-centred design process to the project, it is necessary to present the EID and DB concepts to potential users for their evaluation and consideration. In order to make an early human factors comparison of the two designs, static rapid prototypes of each have been produced using standard desktop software.

Two iterative studies were conducted as part of this rapid prototyping phase, both with related aims and objectives. Study 1 was a questionnaire to determine user requirements for exactly what information should be presented on the interface and to develop appropriate icons for the relevant parameters. This was followed by Study 2, a desktop presentation study of a variety of driving scenarios on each HMI for user evaluation. In the rest of this paper, we detail these two rapid prototyping studies and discuss their outcomes and implications for future development of the Foot-LITE HMI. It is not an aim of the present study to decide on which of the two concepts will be taken forward for development; further detailed work is planned using the Brunel University Driving Simulator (BUDS) to evaluate the effects of each HMI on driving behaviour.

2 Study 1: User Requirements Questionnaire

2.1 Method

Design. The questionnaire was split into two sections. The first focused on determining what type and format of information should be presented on the Foot-LITE in-vehicle HMI, while the second section of the questionnaire asked participants to rank, in order of preference, a selection of icons which represented different aspects of green and safe driving. These icons were derived from reviewing other standardised icons which are already present in current vehicles (i.e. adaptive cruise control, gear shift indicators etc.), following International Standards Organisation guidelines for in-vehicle icons (e.g., ISO 15008:2003 [7], ISO 11429 [8]), and other icons generated specifically during the present research. Four different icons were selected to represent each of eight different aspects of 'smart' driving. These aspects were: headway, fuel economy, lane deviation, acceleration and braking forces, inappropriate cornering speed, gear shift indicators, approaching hazard warning, and a driver alertness warning.

Participants. The questionnaire was distributed to 20 participants from the Brunel University driving study participant pool. All participants held current and valid driving licences, drove on a regular basis and had at least three years driving experience. In total 15 questionnaires were completed and returned (mean age of respondents 40.1 years; SD = 9.2 years), comprising nine females and six males. In addition to these, 11 subject matter experts (SMEs) representing partners from the Foot-LITE project consortium completed and returned the questionnaire. The SME group primarily comprised males aged 18-59.

2.2 Results and Discussion

The first part of the questionnaire contained several questions designed to address content and format of the information to be presented on the HMI. For content, respondents were asked to indicate five aspects from a suggested list of 20 that they considered to be ‘Essential’, ‘Desirable’, and ‘Least Important’. These responses were then ranked across all respondents in order of indicated importance. The top five rankings were:

1. Fuel economy (as a numeric value – i.e., miles per gallon / litres per kilometre)
2. Real-time traffic information
3. Headway
4. Driver alertness warning
5. Approaching hazard warning

In terms of format of presentation, both the users and the SMEs wanted information (e.g., fuel consumption, braking forces, emissions etc.) to be presented in an instantaneous format (i.e., actual moment-to-moment data) as well as an average for the entire journey.

More specific questions on presentation format covered fuel consumption, headway, and emissions data. Both groups clearly preferred miles per gallon for fuel consumption, with other potential options being actual fuel used, cost of fuel used, or a graphical format. A simple generic representation of headway information (i.e., safe, dangerous etc.) was also favoured by both the user and SME groups. An option on actual, numeric data to be presented alongside resulted in a preference for time headway (in seconds) over distance or relative speed.

The presentation of emissions data (e.g., CO_2, NO_x etc.) split the respondent groups. Two thirds of users and half the SMEs wanted emissions information to be presented to them while driving. When asked what types of emissions they wanted to include on the display, half of the respondents stated CO_2 plus other emissions, a quarter only wanted CO_2, while the remainder did not know.

The second section of the questionnaire was concerned with icon presentation. Respondents ranked icons in terms of their preference. They were also encouraged to suggest combinations of icons or any amendments that would, in their mind, make an icon clearer to understand. The preferred icons for each driving parameter were aggregated across respondents to determine which icons would be used in study 2.

As well as rating their preferences, the respondents gave some useful feedback about icon design. Key points from these comments related to advice on cornering speeds and representation of gearshift information. Icons for cornering speed received a mixed response. With further probing it transpired that participants did not want to receive such information while actually driving the corner (as was intended), as this could be distracting. Meanwhile, responses from SMEs and users differed for the gearshift indicators. A simple numerical gear icon was preferred by users over a more elaborate image of a gear 'gate' pattern. On the other hand, SMEs preferred the gate, but since they also rated the simpler icon a close second, the latter option was chosen to take forward.

3 Study 2 – Desktop Evaluation

3.1 Method

Design. The principal aim of the desktop study was to evaluate users' subjective responses to the two candidate designs for the HMI. The output of the user requirements questionnaire was used as input to the EID and DB designs described earlier. Information content and format was incorporated into the prototypes to reflect the opinions of users and SMEs as found in Study 1, with icons for information presentation being taken from the selection chosen by participants. A series of five driving scenarios was developed to represent various aspects of safe and/or eco-driving, and static exemplars for each version of the HMI were constructed to represent these scenarios. Both positive (i.e., desirable) and negative (undesirable) situations were represented. It is important to note that the scenarios and the associated HMI representations were carefully designed such that the information presented across each interface (EID and DB) remained the same – it is merely the format of presentation which was varied and evaluated. The scenarios were designed to represent likely situations which may occur during normal driving, with each interface presenting comparable information.

Thus the experimental design comprised one independent variable (HMI design – EID vs. DB), while dependent variables covered performance measures of response times and accuracy in interpreting the scenarios. Qualitative analyses of participants' descriptions of the displayed scenarios were used to infer the accuracy of their understanding. In addition, participants were asked to complete the System Usability Scale (SUS; [2]) as a quantitative reflection of their subjective opinions on usability for each HMI design. All participants were shown the scenarios for both HMI options in a counterbalanced repeated-measures design.

Participants. Ten non-expert participants (mean age 43.8 years; SD = 10.6 years) were recruited from the Brunel University driving study participant pool, of whom six were female and four were male. All participants held current and valid driving licences, drove on a regular basis and had at least three years driving experience. These participants were a different sample from those selected for the questionnaire study. A minimum of ten participants was needed for the study in accordance with SAE Recommended Practice J2364, which suggests that for early development phases when using a mock-up or computer simulation, static task time averaged over ten participants should be less than 15 seconds [5].

Procedure. The desktop evaluation took place in a laboratory setting with the scenarios and interfaces being presented on a laptop PC. Participants were given a brief introduction to the Foot-LITE project and the aims of the study, and were informed of the basic principles of 'Smart' driving. In addition, participants were given a basic overview of the principles of each interface design (EID and DB). Following the briefing, the Smart driving scenarios for one of the interfaces were presented one at a time, followed by the scenarios for the other interface. As well as counterbalancing of the HMI variable, order of presentation of the scenarios was randomised to minimise any learning effects. After each scenario was shown, participants were asked the same set of questions:

1. What did this scenario mean to you?
2. What aspects indicate this?
3. How would you change your driving to rectify this situation?

Responses to these questions were recorded verbatim for further subjective analysis and to assess the accuracy of their response (i.e., did they identify what the interface was intending to display). Response times were also recorded with respect to their initial understanding of the display (i.e., how long it took them to verbalise what they saw on the display). After all scenarios were completed for one HMI design, participants completed the SUS questionnaire Following completion of the SUS questionnaire, participants were asked other more open questions regarding their thoughts on best or worst aspects of the interface, aspects they would change, and finally at the end of the study which interface they ultimately preferred.

3.2 Results and Discussion

The response time for each participant to verbalise their interpretation of the scenarios was recorded. Absolute time to respond was analysed, irrespective of whether the response was correct. Mean response times for the EID were 0.4s faster than the DB interface (8.0s vs. 8.4s respectively), although a Wilcoxon test revealed that this difference was not statistically significant ($Z = -0.56$; $p = 0.58$). Furthermore, the standard deviation of response times for the EID was also lower than the DB (4.0s vs. 5.1s respectively), suggesting more consistent (and maybe therefore predictable) response times. It is notable that the response times recorded here are well within the 15 second rule for static task completion as suggested by Green [5] and as part of SAE Recommended Practice J2365, thus implying safe use of either of these in-vehicle HMIs while driving. Both interfaces showed some degree of a learning effect, in that response times reduced for the scenarios presented later.

When reviewing the transcripts, a common theme emerged that users were either slow to grasp or misunderstood the EID interface with respect to headway, interpreting the display as representing an obstacle or hazard instead – as some sort of collision warning system. These results indicated that headway needs to be made clearer to users, either by explanation beforehand or through a change to the design. Conversely users were quicker to identify the scenario which represented poor fuel economy and excessive acceleration with EID compared to DB.

Accuracy of participants' responses to the scenarios was coarsely classified into 'fully correct', 'partially correct' (i.e., some elements of safe and/or eco-driving were not correctly identified), or 'incorrect'. Approximately one-third more participants correctly identified the scenario with the EID interface compared to the DB display. At the same time, more participants incorrectly identified the scenario with EID. Thus more participants only partially identified the scenario with the DB compared to EID. With more fully correct responses on the EID, the results suggest that this interface allows both the safety and fuel economy aspects of the design to be more clearly identified. However, it is a notable concern that five participants could not identify correctly any aspect of the interface, with all of these incidents occurring on the very first slide presented to the participants. Again, this implies that there is a steeper learning curve with the EID and highlights the need for a detailed explanation or 'tour' of the interface before use in an actual driving situation.

A potential reason why the DB interface may not have performed as well in these initial tests may be the use of warning icons, which are notoriously misunderstood or ignored, particularly in motor vehicles. A study conducted by the AA in 2006[2] found that almost half of women and a third of men could not correctly identify symbols for frequently used functions or basic warning lights.

The mean SUS scores showed that the DB design was rated higher than the EID (74.1 vs. 67.8 respectively), but a Wilcoxon test revealed that this difference was not significant ($Z = -0.65$; $p = 0.61$). As with response times, the standard deviations in the data again indicated more consistent ratings for the EID interface. Thus there was a larger discrepancy between those who liked or disliked the DB interface. Moreover, despite the mean rating for the EID interface being lower than the DB, more participants rated the EID higher than DB. Five participants rated EID higher, four DB higher while one gave identical ratings.

Finally, analysis of participants' responses to the general questions for each interfaces revealed some recurring comments which may be used to form the basis of future iterations to both the DB and EID interfaces. Other comments supported proposed aspects of the individual interfaces, particularly with the EID. For instance, participants clearly linked their acceleration/braking patterns directly to fuel economy with the EID design. This represents a significant achievement for the EID in helping drivers to understand key factors in eco-driving and linking these to positive changes in their driving behaviour. The EID interface also integrates such information, by keeping all aspects within the 'Green Zone' to maximise fuel economy. Conversely, participants also noted this as a potential limitation with the DB interface, in that it requires the user to look in two separate places, hold this information in memory and then make a mental leap to link the two together.

A very clear response from the vast majority of participants regarding the EID interface was that after an initial confusion as to what the display was showing, they all quickly learned to understand the display. A degree of confusion was to be expected given the limited exposure to the interfaces, particularly for the EID interface as it is a novel design, and thus will be unfamiliar to car drivers. If the EID design should be taken forward to development, then a clear explanation of the interface, or brief tour, would be needed to overcome the learning effect.

On the DB display, the driving information (journey time, fuel consumption etc.) aspects received mixed reviews from the participants. Some stated that the

[2] http://www.theaa.com/motoring_advice/breakdown_advice/warning_lights.html

information was useful and gave lots of useful detail, while others suggested that there was too much information and they would not want this to be displayed during driving. Other suggestions were that the DB interface was a little inconsistent with respect to how some information was presented as what the driver 'should' do (e.g. change to 4th gear), while other information was feedback on what the driver 'did' do (e.g. cornering speed was too fast). On the positive side, participants liked the fuel economy gauge and gearshift indicator, as well as the lane deviation information and headway representation. Overall the DB interface was well received by the participants who found it easily understandable. Some stated that the design was recognisable for car drivers, being similar to existing displays, whereas EID was a new concept for drivers to engage with.

After completing the study, participants were asked which interface they preferred. Six participants stated a preference for the DB design, two for EID and two had no preference. This split was also reflected in the SUS ratings, with those who stated a preference for a particular interface rating it approximately 20 points higher than the other. Those who stated no preference rated both interfaces approximately the same on SUS. However, it is interesting to note that those who preferred the DB design still performed better with EID, generally responding 0.7s faster to each Smart driving scenario and correctly identifying more EID scenarios when compared to DB information. Meanwhile, the two participants who preferred the EID also performed better with this interface.

4 General Discussion

Results from the user requirements questionnaire suggested what information participants wanted to see on the Foot-LITE system, and also gave a clear indication on what format they wanted the relevant information to be presented in. In addition, the process generated a 'bank' of icons to represent different aspects of Smart driving, and icon preferences were recorded. These responses were used to develop the two candidate HMI designs taken forward into the desktop evaluation study.

As an early human factors analysis of proposed interface designs for a 'Smart' driving advisor, the current study has served its purpose. Compared to the original specification from the CWA output [1], participants viewed fuel economy as a key component of eco-driving, while headway, driver alertness and hazard warnings were preferred aspects of safety information. Conversely, it was clear from the questionnaire that feedback on cornering speed was not seen as beneficial while driving the corner, due to the driver being otherwise occupied during this task. There was a clear preference for real-time feedback on driving on a moment-to-moment basis.

The desktop evaluation revealed that whilst drivers largely preferred a traditional dashboard-style layout, the more adventurous ecological interface design had performance advantages once the initial learning curve had been established. Participants also made clearer links between their driving style and changes to fuel economy with the EID interface, ratifying the integrated and direct perception nature of this design. Safety aspects of driving seem to be well represented on both designs, with the pop-up icons of the DB interface preferred.

The subjective responses given by the participants form a good basis for potential iteration of both interfaces. Recommended changes on the EID include the removal of real-time warning information regarding inappropriate cornering speed, which was deemed confusing and potentially distracting if given while negotiating the corner. Furthermore, safety aspects should be made clearer – perhaps using pop-up icons as with the DB, use of the eco-driving divisions on the display should be reconsidered, and gear change information should be incorporated onto the EID, given that this was popular on the DB. Specific recommendations for the DB interface were that journey information should be limited, the fuel economy gauge could be changed to a Smart driving meter, giving an indication of safety performance, and gearshift information should be simplified. The next stage of the research is to refine each interface design based on the output of the current studies, and to take both options forward to more dynamic testing in the Brunel University Driving Simulator.

Acknowledgements. Foot-LITE is sponsored by the EPSRC, the DfT, and the Technology Strategy Board under the Future Intelligent Transport Systems initiative. The Foot-LITE consortium is comprised of: MIRA, TRW, Autotxt, Hampshire County Council, the Institute of Advanced Motorists, Ricardo, TfL, Zettlex, the University of Southampton, Newcastle University, and Brunel University.

References

1. Birrell, S.A., Young, M.S., Stanton, N.A., Jenkins, D.P.: Improving driver behaviour by design: A Cognitive Work Analysis methodology. In: Applied Human Factors and Ergonomics 2nd International Conference, CD-ROM (2008)
2. Brooke, J.: SUS: A "quick and dirty" usability scale. In: Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, A.L. (eds.) Usability Evaluation in Industry, pp. 189–194. Taylor and Francis, London (1996)
3. Burns, C., Hajdukiewicz, J.: Ecological Interface Design. CRC Press, Boca Raton (2004)
4. Gibson, J.J., Crooks, L.E.: A theoretical field-analysis of automobile driving. The American Journal of Psychology 51, 453–471 (1938)
5. Green, P.: Estimating compliance with the 15-second rule for driver-interface usability and safety. In: 43rd Annual Meeting of the Human Factors and Ergonomics Society (1999)
6. ISO 11429: Ergonomics – System danger and non-danger signals with sounds and lights
7. ISO 15008: 2003: Road vehicles – Ergonomic aspects of transport information and control systems – Specifications and compliance procedures for in-vehicle visual presentation (2003)
8. PACTS: Beyond 2010 – a holistic approach to road safety in Great Britain. Parliamentary Advisory Council for Transport Safety, London (2007)
9. Vicente, K.: Cognitive work analysis: Toward safe, productive, and healthy computer-based work. Lawrence Erlbaum Associates, Mahwah (1999)
10. Young, M.S., Birrell, S.A., Stanton, N.A.: Safe and fuel efficient driving: Defining the benchmarks. In: Bust, P.D. (ed.) Contemporary Ergonomics 2008, pp. 749–754. Taylor & Francis, London (2008)