Human factors research to support effective evaluation of in-vehicle systems: A case study example

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Abstract

Intelligent Transport System (ITS) technologies are increasingly being used in a number of ways with drivers now having access to a range of information, communication and entertainment systems, as well as driver aids, collision avoidance technologies and a wide range of portable devices. While it is clear that the integration of ITS technologies within the vehicle could potentially have a range of safety and performance benefits, they also have the potential to degrade safety if not designed or used properly. Before entering vehicle fleets, new technologies need to be rigorously evaluated to ensure that they do not impose a safety risk. At MUARC the mid-range driving simulator has been a critical tool for such evaluations. This paper will outline how our research is supporting the effective evaluation of in-vehicle technologies through the discussion of a recent evaluation of an in-vehicle system to warn drivers of an approaching emergency vehicle. Through systematic scenario design and behavioural analysis in the driving simulator it was possible to determine when drivers first detected the warning through analysis of eye-movement data, and to determine when they first responded through analysis of driving performance data. While the device had positive effects on safety through reductions in driver speed, the data provided for a theoretical consideration of how drivers respond to warning systems in this context. Warning signals need to provide the driver with reliable information in a salient manner, minimising distraction, and issues relating to the warning timing and mode of presentation are critical here. Priming theory emerged as a likely mechanism underpinning the observed safety benefits and is generalisable to other settings where an advisory warning is presented before the threat is perceived.

Keywords

Emergency vehicle, advisory warning, in-vehicle technology

Introduction

In-vehicle technologies are increasingly being used in a number of ways within modern vehicles to enhance driver performance and safety. Examples of in-vehicle systems include Intelligent Speed Adaptation Systems, Adaptive Cruise Control, Forward Collision Warning Systems, Rear Collision Warning Systems, Seat Belt Reminders, Lane Departure Warning Systems, Lane Keeping Assistance Systems, and Brake Assist/Forward Collision Mitigation. Further information about the range and description of technologies is available elsewhere [1-3].

The integration of in-vehicle technologies has the potential to have a range of safety and performance benefits. However, there are concerns that the sheer number of devices making their way into the vehicle and their expanding functionality will make them less usable, overload drivers and distract them from the primary driving task. HMI is an essential element contributing to road safety and driver comfort. Both standardisation and legislation play an important role in the design of HMI at the national and international levels. However the constant proliferation of new devices and functions may jeopardize the safety of the driver, passengers and other road users when devices are misused intentionally or unintentionally due to the poor design of the HMI. With an increase in device availability and decrease in price, a larger and wider proportion of the population are now new consumers, suggesting that more and more technologically inexperienced users will interact with increasingly complicated systems [4].

As a result there has been a push not only to establish serviceable design principles aimed at improving ergonomics and minimising the level of distraction imposed by in-vehicle systems, but to also develop a set of valid, simple and cost effective methods and tools for evaluating device impact. It is important that new technologies are rigorously evaluated prior to entering the vehicle fleet to understand how drivers respond to the systems and to understand the system effects on safety. When it comes to evaluating any type of in-vehicle system, researchers (and automotive design teams for that matter) are faced with a myriad of methods, tools and measures that they can choose from. As noted in our other work [4], these tools and methods range from subjective methods such as questionnaires or scales that measure user acceptance or mental workload, through to direct and surrogate measures of driving performance (e.g., driving simulators, visual occlusion test, etc) and physiological measures (e.g., eye glance behaviour, heart-rate variability, EEG). The methods and tools which are most appropriate for a particular evaluation will depend on factors including the type of system being evaluated, the aim of the evaluation, the maturity of the system in terms of the stage of the system-development lifecycle the system is at, and the environment in which the testing will be carried out. As part of our broader research program addressing the design and evaluation of in-vehicle technologies and systems we have attempted to make the task of selecting appropriate evaluation methods and measurement parameters simpler [5].

Many of the traditional methods utilised by researchers often revolve around laboratory-based evaluations to assess potential impacts of technologies on subsequent safety. At MUARC the mid-range driving simulator has been a critical tool for such evaluations of various technologies. The simulator is described briefly here before considering how it has been used in recent system evaluations.

The MUARC advanced driving simulator

The advanced driving simulator located at MUARC is the most advanced driving simulator in the Southern Hemisphere. It consists of a Holden Calais sedan with normal interior features, surrounded by two projection screens (Figure 1). The major projection screen is located at the front of the vehicle, and one is located behind it. From the driver's eye point the screen in front of the car provides a field of view subtending angles of approximately 180 degrees horizontally and 40 degrees vertically. The rear screen provides a field of view subtending angles of approximately 60 degrees horizontally and 40 degrees vertically. Three BARCO 700 HQ projectors convey images of traffic scenes onto the front screen. Special electronics blend these individual images into one quasi-continuous image. The projectors are adjusted so that all scene objects are displayed in their correct geometric locations as viewed from the central eye design point. The images displayed on the screens are generated by a Silicon Graphics Onyx computer that updates the images on all channels at a rate of 30 Hz.

A quadraphonic sound system provides realistic traffic sounds such as tyre squeals, engine noises, horn blasts, low frequency vibrations, and emergency vehicle sirens. The system simulates pulse Doppler and atmospheric damping effects. Simulations are designed and run using the following computers: a Silicon Graphics Indy (primarily for developing, running and replaying simulation scenarios); a Silicon Graphics Onyx (primarily for graphics generation, handling vehicle data inputs and outputs, controlling the audio system and vehicle dynamics, and road database development); and a PC (for generating sounds). The experimenter commences and runs driving simulations from a control room located adjacent to the simulation room.

The following sections of the paper present a brief case study illustrating how the MUARC simulator has been used to evaluate the effects of in-vehicle technology on driver behaviour (further details available elsewhere [6]). This case study also highlights some of key functional issues to consider when considering the introduction of additional and more complex systems into the vehicle.

Figure 1. The MUARC advanced driving simulator

Case Study: Evaluation of an emergency vehicle warning system

Project Aim

The major aim of this research was to establish whether an Advanced Warning Device (AWD) had any effect on the safety of the interactions between emergency vehicles and other drivers and, if so, whether it had a positive or negative effect on the safety of those interactions. The AWD was designed to provide a safer driving environment for both on-call emergency vehicles and the general motoring public. This was achieved by placing the AWD, comprising both visual and auditory indicators, on the lower left corner of the windscreen in accordance with instructions from the project sponsor.

The AWD is designed to work in conjunction with the emergency vehicle's existing sirens and flashing lights. Were it to be used in the field the module would be activated when an on-call emergency vehicle is within a 300m – 400m radius. Drivers would therefore be provided with advanced warning of approaching on-call emergency vehicles, in theory allowing them sufficient time to safely provide a clear path for the on-coming emergency vehicles and thus potentially reducing the risk of any possible collisions.

Scenario Design

In any simulation study it is critical that the scenarios developed are representative of the defined crash types and designed so as to elicit the desired behaviours for measurement and analysis. In order to measure the effects of the AWD on driver behaviour, it was critical that drivers were placed in realistic and relevant high-risk scenarios that resembled, as closely as possible, the high risk situations that lead to emergency vehicles being involved in crashes and near misses on the road. There was however very little information available about the crash types and characteristics of emergency vehicle crashes in Victoria, and hence little information to use as a basis for creating appropriate scenarios for measuring driver responses to the AWD. The first stage of this research aimed to provide this information [7].

The three most prominent crash types involving emergency vehicles that emerged from the Victorian crash data, and that could potentially be resolved using the AWD, were: adjacent, involving a side-impact collision; right-turn, involving a vehicle colliding with another vehicle performing a right-turn across; and car-following, which involves a front-to-rear collision. Further selection and refinement of specific scenarios for the simulator study occurred via a workshop conducted at MUARC with representatives from the Victoria Police, Metropolitan Ambulance Service, and the Metropolitan Fire Brigade.

Results

Dependent measures analysed for all three crash types included mean speed, braking, steering wheel movements, and eye movements as measured by the FaceLab system. Indicative results are presented here with further details being available elsewhere [6]. Data are presented for the three experimental conditions (or warning types): AWD (Emergency Services Avoidance Technology) which involved the AWD and an emergency vehicle with conventional lights and sirens; the emergency vehicle only condition with lights and sirens active; and a control condition involving non-emergency vehicles.

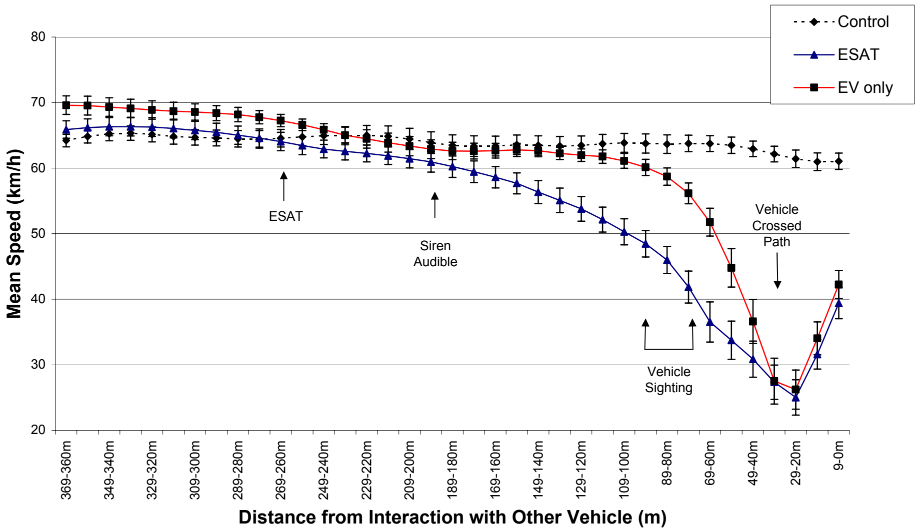

Figure 2. Profile of mean speed (km/h) ± SE on approach to the ADJACENT event for control, emergency vehicle, and AWD conditions

In the adjacent scenario the participants were driving through an intersection on a green traffic light when a car appeared from the left approach. Figure 2 shows the speed profile on approach to the adjacent intersection event. There was a significant interaction between the two factors, *warning type* and *distance* ($p<0.05$). Mean speed did not vary in the control condition on approach to the intersection ($p > 0.05$), but did drop significantly for both EV-only and AWD conditions ($p<0.05$). The interesting finding is that compared to the control condition, there was an earlier reduction in mean speed when the AWD was activated than for the EV-only condition.

While the simulator data tell us when drivers first responded to the events, the analysis of eye movement data provides an insight as to when drivers first detected the key stimuli. A commonly used measure of eye movements is the saccade, broadly defined as rapid eye movements between points of fixation. While not reported here, the eye movement data showed increased scanning of the environment in the AWD condition than for EV-only and control conditions. Scanning appeared to increase markedly when the AWD device was activated, suggesting that drivers were actively searching the visual environment for the EV.

Subjective Data

In addition to the simulator and eye movement data, participants were asked a series of questions about their experiences with the AWD.

To what extent would the visual component of the in-vehicle warning device be helpful in alerting you of an approaching emergency vehicle? Almost one third of participants felt that the visual display component of the in-vehicle device would be a great help in alerting them to the presence of an emergency vehicle, and 95% felt that it would at least be of some use (Figure 3).

To what extent would the auditory component of the in-vehicle warning device be helpful in alerting you of an approaching emergency vehicle? Forty percent of participants felt that the auditory tone component of the in-vehicle device would be a great help in alerting them to the presence of an emergency vehicle (Figure 3). A greater proportion of participants rated the auditory tone as being of greater use compared to the visual display.

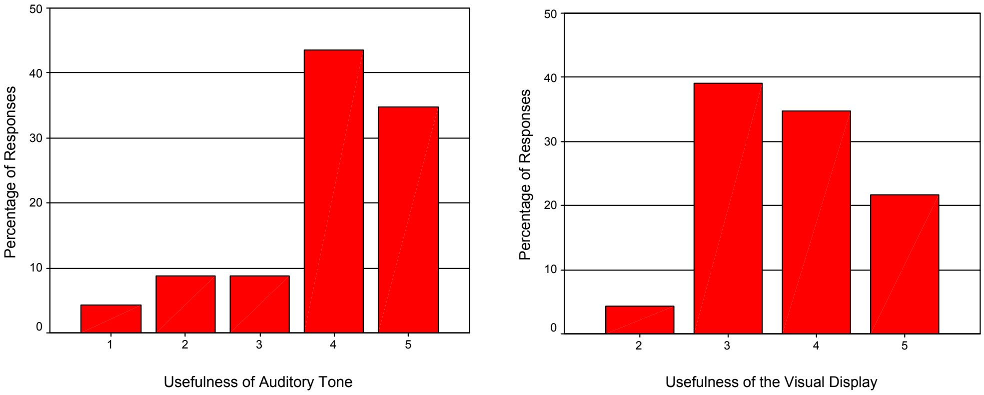

Figure 3. Ratings of the usefulness of the auditory and visual warning for alerting to the presence of an emergency vehicle (0 = No use, 5 = Of great use)

Participants were also provided with the opportunity to provide general comments about their experiences with the device. Some negative comments included: once the emergency vehicle had passed the device was quite distracting; the device provided no sense of direction and speed of the emergency vehicle like you get with a siren, and; in some cases the noise and/or flashing flights may panic some drivers. Further positive comments included: it was very useful for alerting drivers to the presence of emergency vehicles, especially when at intersections and when the sirens could not be heard until the last minute; the visual device would be beneficial, especially when you have music playing in the car, as it would give the driver a chance to turn off the music and listen to where the emergency vehicle is coming from.

Discussion

The advanced warning provided by the AWD resulted in a greater reduction in mean speed compared to the emergency vehicle only condition. Mean speed remained constant in the control condition. This is not surprising because in this condition the behaviour of the control vehicle was not expected to cause any major changes in driver behaviour. Nonetheless, it was important to collect baseline data to account for any potential changes to driver behaviour that may have occurred on approach to an adjacent intersection.

While other measures of driving performance were collected [6], in the interests of brevity only speed data were presented here. The reason for this is because speed is a fundamental determinant of crash and injury risk. The faster the travel speed, the more rapidly information from the traffic environment must be processed. When the information processing demands in any given driving situation approach the limits of an individual's capacity, the potential for a crash rises substantially.

Of even greater importance is the relationship between speed and injury risk in the event of a crash. According to these relationships, the outcome of a change in mean speed may be described in terms of power functions, with the size of the power increasing as crash severity increases. Research has shown that travel speed and fatal injury risk are related through a fourth power relationship, serious casualty crashes through a third power relationship and casualty crashes through a second power (or squared) relationship [7]. Travelling at 70 km/h instead of 60 km/h, for example, results in an approximate 80-90% increase in the risk of fatal crash. In many common crash types, the speed at impact is well within the speed limit but beyond the biomechanical tolerances of humans and the capacity of vehicles to protect their occupants [8]. On the basis of the laws of motion and the findings of research on speed, it can be concluded that even small reductions in travel speed or of impact speed will lead to substantial reductions in crash and injury risk.

In addition to objective measures of driving performance, participants' subjective experiences with the AWD device were also collected in this study. The ratings for the various questions suggest a highly positive response to, and experience with, the in-vehicle device. Both the visual and auditory components of the device were believed to have benefits in providing advanced warning to the participants, and thus the perceived safety of the interactions with emergency vehicles was higher for almost all of the participants. The survey data in essence reflect the driving performance data. That is, the participants indicated that the in-vehicle device resulted in a reduction in vehicle speed, an increase in visual scanning, and an increase of their preparedness for the interaction with the emergency vehicle. In combination with other performance measures not reported here [6], the data show positive effects of the AWD device in the form of increased preparedness to respond to the emergency vehicle.

Implications

The results from this evaluation yield a number of questions that relate to the functionality of this particular system, the implementation of such as system in the vehicle fleet, and implications for other in-vehicle systems more broadly. These are considered in turn.

Firstly, there is clearly scope to improve the functionality of the AWD. Some of the comments received from the participants concerned the lack of directional cues provided by the warning. Hence while participant ratings of device utility were high, there is potential to enhance system effectiveness and acceptability further by providing more targeted warnings. Device placement within the vehicle was not examined in this study and would need to be examined, particularly if directional cues were incorporated into the visual component of the warning.

Secondly, in terms of challenges associated with implementation, several issues relating to the potential effectiveness of the AWD device in the field should be considered. How drivers' responses to the AWD device might change over time (behavioural adaptation) would be of great interest. The potential for the proximity-based warning to yield an acceptable level of false alarms also needs to be established. It would be interesting conduct a small trial to consider how driver responses to the AWD might change over time and to determine how the system performs in the field. Another issue is whether the changes in behaviour associated with the activation of AWD would actually result in a reduction in crashes, near misses, and response times involving emergency vehicles. This would likely require several years of exposure to AWD in the community before any meaningful crash analyses could be conducted.

Finally, there are some outstanding research issues to consider. The importance of understanding the functional requirements for in-vehicle systems such as this one is widely recognised by researchers and this research leads to a number of questions as we consider the implications for other systems. Much previous work in road safety has explored issues including the influence of warning timing, urgency, and mode of presentation on the behavioural responses of drivers [10,11]. Clearly, the timing and urgency of a warning should be dependent upon the system aims, that is, whether it is designed to simply advise the driver to redirect attention, or whether in the case of a collision avoidance system it is designed to illicit a more immediate response. For advisory warning systems such as this one, conventional thinking has suggested that warning intervals of less than around 1 second are appropriate, a rationale being the potential for driver distraction and the annoyance that might arise from having a warning activated much before the threat can be perceived by the driver. This study however found potential safety benefits using a warning interval of up to around 3 seconds (the interval between the AWD activation and when the EV siren was audible). This has implications for other advisory in-vehicle systems that might operate in a similar manner. An example here might be an in-vehicle device that warns a driver to the presence of a train at a level crossing. Here again, the warning might be provided to the driver before he/she perceives the presence of the threat (the train). In terms of what may be driving the results found, response priming may be an underlying mechanism here but requires significantly further examination [12]. Response priming has been well researched in experimental psychology and in essence relies upon the strength of an association between a cue and a target stimulus to facilitate a more rapid response.

In closing, it is critical that human factors research keeps pace with the rapid emergence of devices and systems onto the automotive market. Further research is needed to explore fundamental issues, well researched in domains such as aviation, relating the device functionality and the basics of when to present a warning and how to present it. This work is fundamental to decrease the chances of their being negative safety outcomes when multiple systems are integrated within vehicles. To support simulator evaluation research there is a prominent role for naturalistic driving research, which will form a key part of our evaluation methodology in the future.

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