EVALUATING IN-VEHICLE INTELLIGENT TRANSPORT SYSTEMS: A CASE STUDY

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ABSTRACT

The SafeCar project is designed to assess driver adaptation to, and acceptability of, a collection of in-vehicle intelligent transport systems. This paper describes the functional characteristics of the various on-board technologies equipped to 15 SafeCar test vehicles and the final design of the on-road study evaluating the safety benefits of the technologies.

INTRODUCTION

The term Intelligent Transport Systems (ITS) refers to the bringing together of advanced computer, communications, sensor and vehicle control technologies to transport systems in order to enhance safety, increase efficiency and mobility and reduce pollution and other unwanted environmental byproducts of transportation (Regan, Oxley, Godley & Tingvall, 2001). Various in-vehicle ITS technologies are already commercially available in Japan, Europe and North America. Some, such as Adaptive Cruise Control, are now entering the Australian market. Many of these systems have significant potential to enhance the safety of drivers and other road users (Rumar et al., 1999; Regan, Oxley et al., 2001). The actual benefits of these systems, however, are currently unknown, because the technologies have not been deployed on a large enough scale for long enough for crash numbers to be a reliable indicator of a change in safety (Rumar et al., 1999). In the meantime, a number of on-road research trials are being conducted around the world to enable more accurate predictions to be made of the safety benefits of the technologies. In Europe, the primary focus of these studies has been on Intelligent Speed Adaptation (ISA), which warns the driver if the posted speed limit is exceeded or automatically limits the speed of the vehicle to the posted limit (e.g. Besseling & van Boxtel, 2002; Várhelyi, 2001). In both North America and Japan, field trials have tended to focus on the assessment of in-vehicle ITS warning and avoidance systems for preventing or minimising the impact of collisions of various kinds.

The Australian SafeCar project (Regan, Mitsopoulos, Tomasevic, Triggs & Healy, 2001) is one of a growing number of international studies concerned with evaluating the potential safety benefits of in-vehicle ITS. It is the first study in the world to examine in a field trial the interactive effects on driving performance of ISA in combination with other in-vehicle ITS systems. The study is a collaborative research project involving the Victorian Transport Accident Commission (TAC), the Monash University Accident Research Centre (MUARC) and the Ford Motor Company of Australia. A primary aim of the project is to stimulate demand, initially by corporate car fleet owners and in the longer term by the general community, for in-vehicle ITS, which are estimated to have significant potential to reduce road trauma in Australia.

An earlier paper presented at the 2001 Road Safety Research, Policing and Education conference (Regan, Mitsopoulos et al., 2001) described the aims of the SafeCar Project and the various activities undertaken in developing and testing two prototype vehicles equipped with various ITS technologies. It was foreshadowed in that paper that, in Phases 3 and 4 of the project, 15 Ford test vehicles, equipped with a similar mix of ITS technologies, would be developed and evaluated. The present paper describes the Phase 3 and 4 activities undertaken since the last paper was presented. The first section of the paper describes the various technologies equipped to the Ford test vehicles. The second section describes the experimental design of the on-road study, which is being conducted to assess the effects of the technologies on driving performance, driver acceptability of the systems, and the technical reliability of the systems.

DESCRIPTION OF THE SAFECAR SYSTEMS

Phase 3 of the SafeCar Project commenced in July 2001 and concluded in September 2002. During this Phase, 15 Ford passenger sedans and wagons were equipped with several ITS technologies and other systems to support the experimental aims of the on-road evaluation. The functional characteristics of each of these technologies are summarised below.

ITS Visual Display. The ITS visual display unit displays all visual warnings and messages issued by the SafeCar systems. The display is located to the left of the driver on the dashboard and consists of a 3.8” Liquid Crystal Display. The display is shown in Figure 1.

ITS Audio System. The function of the ITS Audio System is to present all auditory warnings and messages issued by the various SafeCar systems. The levels of the auditory messages are loud enough to be heard in all driving conditions, but are not loud enough to startle the driver and are also unable to be turned off.

Figure 1. ITS display and control panel

Log In System. The purpose of the Log In system is to ensure that the appropriate SafeCar systems are activated when the ignition is turned on. To log in, the driver inserts an “iButton” into a reader unit. The iButton has the appearance of a large watch battery. During log in, which takes around 10 seconds, information specific to each fleet driver stored in the iButton is transmitted to the relevant SafeCar systems. If the iButton is not inserted, a visual and auditory message stating - “*Please insert log in button*” - is presented and repeated for 30 seconds. If the iButton is not inserted at this stage, all system warnings are disabled.

Master Pushbutton. The Master Pushbutton allows non-designated drivers, that is, drivers other than the test drivers in the on-road study (see below), to drive a SafeCar without being exposed to the systems. This will ensure that the data collected for a SafeCar will relate to its test driver’s driving performance only. This is also a duty of care requirement, since only drivers participating in the study will be properly trained to use the SafeCar systems. After initialisation of the SafeCar operating system, the System Override Button, which is located on the ITS Control Panel on the dashboard (see Figure 1), begins to flash. At the same time, the following voice and text message is presented - “*If you are not the designated driver, please press the flashing button*”. Non-designated drivers are required to press the flashing System Override Button. Doing so disables all SafeCar systems for the duration of the trip.

ITS Technologies. Technologies fitted to the SafeCar are divided into two groups: the key technologies, which are of primary interest in the study, and the background systems, to which all participants are exposed. The key systems are Intelligent Speed Adaptation - Actively Supporting (ISA-A) and Following Distance Warning. The background systems are Seat Belt Reminder, Daytime Running Lights and Reverse Collision Warning.

ISA-A. The actively supporting variant of ISA is designed to warn the driver when he or she is exceeding the posted speed limit for a given location. Information regarding the current position of the vehicle and the speed limit that applies to that location is determined by comparing the vehicle’s location coordinates obtained from a Global Positioning System with a digital map database containing information about the road network and posted speed limits.

ISA-A consists of a two-stage warning system. While the vehicle is travelling below the posted speed limit, no warnings are issued. The stage 1 warning is presented immediately after the posted speed limit has been exceeded by 3 km/h or more. This warning takes the form of a static visual scaled-down version of a standard speed sign, which appears on the ITS display screen (see Figure 2). The static visual icon is accompanied by a single short duration auditory tone.

Figure 2. ISA visual warning icon

The stage 2 warning is presented if the vehicle continues to exceed the speed limit by 3 km/h or more for a period of 5 seconds or more. As with the stage 1 warning, the speed limit icon is displayed, however, in stage 2, the visual icon flashes and is accompanied by upward pressure on the accelerator pedal. It is possible for the driver to overcome the resistance in the accelerator pedal by 'kicking down' on the accelerator should the driving conditions require it (Regan & Tomasevic, 2001).

Following Distance Warning. The following distance warning system is designed to issue visual and auditory warnings to the driver when he or she is travelling too close to a vehicle in front. The system, the Eaton Vorad

Technologies EVT-300, utilises radar signals to establish the time headway between the host vehicle and the vehicle ahead. There are six levels of warning, which increase in intensity as time headway decreases. These warnings are both visual and auditory. The visual warnings are displayed on the right side of the ITS display and resemble a ladder with 7 rungs (see Figure 3). As the time headway between the host vehicle and the vehicle in front decreases, the bars of the ladder fill with colour starting with the top rung and moving down as the time headway decreases. The level 1 warning is presented when the time headway drops below 2 seconds and consists of the first bar being coloured yellow. For level 2 and 3 warnings, the next two bars are also coloured yellow. When the time headway drops below 1.3 seconds, the fourth bar is coloured red and the entire ladder begins to flash. The level 5 warning is presented when time headway drops below 1.2 seconds. The fifth bar turns red while the ladder continues to flash. The sixth and final warning is presented when time headway drops below 1.1 seconds. At level 6, the last bar of the ladder turns red and the ladder continues to flash. At this stage the auditory warning is also presented (Regan & Tomasevic, 2001). Figure 3 illustrates the following distance warning ladder.

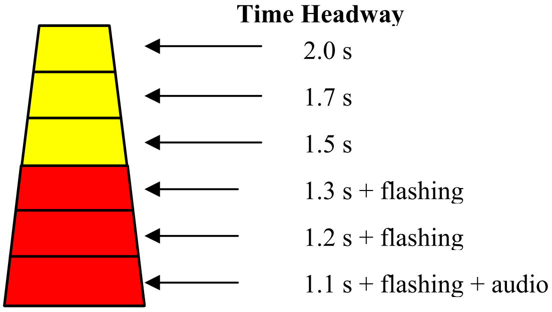

Figure 3: Following Distance Warning Ladder

Figure 4: Seat Belt Reminder visual icon

Seat Belt Reminder. The seat belt reminder system is designed to warn drivers when they, or one of their occupants, is unrestrained. Sensors in each seat detect weights over 15 kilograms and trigger warnings if the seat belt is not fastened. Four levels of warnings are issued and the intensity of the warnings increases as vehicle speed increases. The level 1 warning is presented when the vehicle's speed is between 0 km/h and 9 km/h, inclusive, and consists of a flashing visual icon (see Figure 4) and a static text message stating "Fasten Seatbelt". The level 2 warning, issued when vehicle speed is between 10 km/h and 25 km/h, consists of an identical visual warning to level 1, however, it is accompanied by an auditory warning. As vehicle speed increases, level 3 and 4 warnings are issued in which the repetition rate of the auditory tone increases.

Reverse Collision Warning. The reverse collision warning system is a commercially available system known as the Bosch "Park Pilot". It is designed to prevent collisions with objects to the rear of the vehicle when reversing. The system utilises ultrasonic sensors to detect when a reversing vehicle comes within one metre of an object behind it and triggers five levels of auditory warnings. The level 1 warning is presented when the distance between the vehicle and the object is 80cm to 1 metre. As the distance between the vehicle and the object decreases, the repetition rate of the auditory tone increases. When the vehicle is within 30cm of an object, a continuous, unbroken tone is issued. The reverse collision warning system is automatically activated when the vehicle is put into reverse gear and automatically deactivates when the vehicle is no longer in reverse.

Daytime Running Lights. Daytime running lights are headlights that operate at 80% of normal low-beam brightness and function to increase the visibility of the SafeCar on the road during daylight conditions. These lights turn on automatically when the engine is started and turn off when the engine is stopped.

Message Priority System. The Message Priority system is designed to ensure that if two ITS warnings are initiated simultaneously, only the most critical warning is presented to the driver. This prevents the driver becoming confused or overloaded from multiple warnings.

ITS Control Panel. The ITS Control Panel is located on the dashboard of the vehicle to the left of the driver and contains the Speed Request Button, System Override Button and the Master Volume Control (see Figure 1). The Speed Request Button allows drivers to request the current posted speed limit in any location contained within the digital map. The current speed limit is displayed on the ITS Visual Display as a miniature standard speed limit sign and remains on screen for 3 seconds. As described earlier, during log in, the System Override Button functions as the Master Pushbutton. However, for all designated drivers (i.e. test drivers in the on-road study), pressing the System

Override Button during a trip disables all visual and auditory warnings for a period of 60 seconds. The Master Volume Control allows SafeCar drivers to adjust the volume at which the SafeCar auditory messages and warnings are played. However, it is not possible for the driver to turn off the auditory warnings.

Data Logging. The Data Logging system is designed to collect a wide range of driver and vehicle performance data. These data are recorded and stored on flash memory cards and downloaded manually each month.

Log Out. The Log Out system is designed to record the end of a driving session and update, on the iButton, the number of kilometres travelled during the driving session. To log out, the iButton must be in the reader unit. If it is not, the text and voice message - "*Please insert log in button to complete shutdown process*" - is presented. If the iButton is not re-inserted into the reader unit at this time, shutdown will continue, but the iButton will not be updated.

PHASE 4: ON-ROAD EVALUATION

Phase 4 of the SafeCar Project was due to commence in October 2002. During Phase 4, data will be collected, in an on-road evaluation study involving the ITS equipped cars and in the advanced driving simulator at MUARC, to assess the technical operation of the chosen ITS technologies, evaluate the effects of the technologies on driving performance and safety, and to measure driver attitudes to and acceptance of the technologies. The successful deployment of ITS is contingent upon consumers' acceptance of the technologies. Systems that are not acceptable to drivers will not be purchased nor will they be used. Even if the technologies have the potential to affect driver behaviour in a positive way and to enhance safety, the benefits of these technologies can never be realised if there is little or no demand for the technologies (Mitsopoulos, Regan & Haworth, 2002; Regan, Mitsopoulos, Haworth & Young, 2002). The on-road study constitutes the major research activity of the SafeCar Project and is in itself a carefully designed and controlled experiment. The on-road study is described below.

Participants. Each participant will drive an ITS-equipped vehicle, for business and private purposes, for 16,700 kilometres. This will correspond to about 5 months of driving. During this time different systems in the vehicle will automatically turn on and off in pre-determined orders for each driver. Drivers will be told when and in what order the systems will turn on and off in a Participant Briefing and Training session held prior to the commencement of the study and will be automatically reminded by a voice and text message in the SafeCar when a particular system or combination of systems is about to turn on or off. The 15 Ford passenger cars will be driven, in turn, by two different drivers. Therefore, over the 10 month trial period, a total of 30 drivers will participate in the study. To be eligible to participate, drivers must: be aged between 25 and 64 years; hold a full and current Victorian car driver's licence; have normal hearing and vision, although glasses or contact lenses may be worn; have no known substance abuse disorder; and have a vehicle usage rate of at least 40,000 kilometres per year. Drivers will comprise volunteers from 7 or 8 private and public organisations in Victoria who normally drive a company fleet car for business and recreational purposes. Professional drivers (e.g., taxi drivers) will not be involved in the study.

Design. The experimental design is a mixed design (within-subjects and between-subjects) with two independent groups. Of the 30 participants, one third (n=10) will be assigned to a Control Group and the remaining 20 participants will constitute the Treatment Group.

Treatment Group. For participants in the Treatment Group, the on-road trial is divided into several discrete periods. These are the "Familiarisation", "Before", "During", and "After" periods. The Familiarisation period provides drivers with the opportunity to get used to driving a SafeCar before any ITS technologies, with the exception of the Daytime Running Lights, are enabled and before any data are logged. This period lasts for 200 kilometres. The Daytime Running Lights are enabled for the duration of the trial. Next is the Before period, which is divided into "Before 1" and "Before 2" periods that last for 1500 kilometres each. Baseline performance data are collected during this period, hence no "key" system warnings are issued. During this period the data logger is first activated and stays on for the rest of the trial. It is possible that for part of the Before 1 period participants may drive more cautiously, as they know their data are being logged. During the Before 2 period, the Reverse Collision Warning and Seat Belt Reminder Systems are active. Comparisons between the Before 1 and Before 2 periods will enable the research team to determine whether the introduction of these "background" systems has any influence on baseline driving performance. A total Before period of 3,000 kilometres represents a compromise between the need to practically constrain the total duration of the field trial, and the need to be able to collect enough data points in different areas of the road network to enable meaningful comparisons between baseline driving performance and performance during and after exposure to the various systems.

The purpose of the During periods is to assess the effect on driving performance of the “key” ITS technologies in the SafeCars. The During period is divided into “During 1, 2 and 3” periods with each lasting 3,000 kilometres. Consultation with several overseas colleagues suggested that this would be the minimum acceptable duration of exposure to a system in order for any “behavioural adaptation” to occur. Behavioural adaptation refers to how a driver’s behaviour changes over time as a consequence of exposure to a system or combination of systems. The During 1 period occurs immediately after the Before 2 period. In addition to the Daytime Running Lights, Reverse Collision Warning and Seatbelt Reminder systems, the driver will receive warnings from ISA-A, the Following Distance Warning System, or both systems concurrently. The system or system combination received in each During period will be counterbalanced across drivers to control for any order effects. One driver, for example, might receive warnings from ISA-A in During 1 while another driver might receive Following Distance Warnings, or both ISA-A and Following Distance warnings, during this same period.

Each During period is followed by a 1,500 kilometre “After” period in which the “key” system warnings that were active in the previous During period are switched off. This will enable the research team to assess the strength and nature of any behavioural after-effects that persist after warnings cease. The general question of interest here is whether driving an ITS-equipped vehicle changes the way in which a non-ITS equipped vehicle is driven. The duration of the After periods is shorter than that suggested by our overseas colleagues given the practical need to limit the overall duration of the field trial to 10 months. Longer After periods would have been preferable given that, in the opinion of our overseas colleagues, behavioural adaptation effects following exposure to, for example an ISA system, may persist for up to a year.

Control Group. Only drivers in the Treatment Group will be exposed to the warnings of the ISA-A and Following Distance Warning systems. Apart from that, everything else is the same for the treatment and control drivers.

Training. Training is provided to ensure that participants are able to use the ITS technologies safely and effectively. All participants, treatment and control, will attend an identical briefing and training session prior to driving a SafeCar. The session will last for about 2 hours. Identical training is provided to both Treatment and Control groups to ensure that the training itself is not a potential source of variance between the treatment and control participants. Refresher training is provided to treatment participants only, immediately prior to interaction with the relevant “key” ITS technologies (i.e. ISA-A and Following Distance Warning).

Data Collection and Analysis. Objective performance data will be automatically recorded by the data logger in each vehicle and downloaded regularly. A total of 23 data parameters, including speed and time headway, will be logged at a sampling rate of between 1 Hz and 5 Hz for continuous parameters. The data will be analysed to determine whether there are any differences in driving performance between the Treatment and Control Groups at particular points in the trial sequence as a function of exposure to the various systems.

Subjective data will be collected from both control and treatment participants using questionnaires, informal feedback over the telephone and a focus group. These methods will be used to measure driver acceptability of the ITS technologies over time, perceived mental workload, and other factors (e.g. personal attributes, attitudes towards ITS, attitudes towards driving behaviours addressed by the SafeCar systems, awareness of road safety issues, and attitudes towards road safety countermeasures that target the behaviours addressed by the SafeCar technologies). The subjective data will be collected at pre-determined points during the trial to track changes in the measures over time as a result of exposure to the various systems. There will be six points of intervention during the study for control participants and up to eight for treatment participants.

Procedure. Following recruitment, participants will attend, alone or in small groups, a Participant Briefing and Training session. This will occur immediately prior to the Familiarisation period. Here, they will provide written consent to participate, be briefed on the study and will undertake training in how to operate the on-board systems. They will then be assigned to the Treatment or Control Group and will be issued with a System Operating Manual, an iButton (to control ITS system onset and offset) and other resource documents. Refresher training materials will be issued to Treatment Group participants (only) for use later in the trial. The first wave of questionnaires for collecting subjective data will be administered at the Participant Briefing and Training session.

All data derived from the study will be downloaded into a confidential database located at MUARC. MUARC researchers will phone participants every 2 to 3 weeks to monitor participant progress, address any queries and verify that the on-board systems are changing status as pre-programmed. Separate telephone “hotlines” have been implemented to enable mechanical or technical problems to be reported by participants to the TAC and to enable feedback on usability and acceptability of the systems to be conveyed to MUARC researchers. Once a month, participants will receive in the mail from MUARC an empty flash memory card. This card is to be replaced with the card currently in the vehicle and the used card mailed back to MUARC. On arrival at MUARC, the data will be downloaded into the database. If the logged data analysed by MUARC show that a participant has been driving in a sustained dangerous manner (according to a set of definitions developed prior to the trial), as a duty of care MUARC is obliged to report such instances to the TAC, who in turn will inform the relevant car fleet manager. In the unlikely event that a SafeCar is involved in a crash, logged data may be subpoenaed for use as evidence in a court of law. Participants will be excluded from the study if they are found to drive in a sustained dangerous manner, fail to maintain and secure their vehicle, fail to conform to study requirements, or wilfully damage a SafeCar. Vehicles are returned to the fleet owner after each participant has accumulated 16,700 kilometres. Following this, participants are required to complete a final wave of questionnaires and, if they wish, participate in a focus group to gather additional information about the acceptability of the on-board systems.

CONCLUSION

This paper provides an update on the progress of the Australian SafeCar project, focussing on the final design of the on-board systems and the experimental design of the Phase 4 on-road study. It is the first study in Australia, and indeed the world, to conduct an on-road trial examining the interactive effects on driving performance and safety of ISA *in combination* with other in-vehicle ITS. The study will also provide valuable information on the acceptability to drivers, over time, of the various systems under investigation. This information will serve to identify to what extent the technologies can be expected to be embraced by the community, and to identify barriers to deployment that can then be addressed to maximise acceptance, and as such, the uptake of in-vehicle ITS.

Progression to Phase 4 of the project has highlighted how little practical guidance is generally available relating to the design, specification, testing, deployment and evaluation of in-vehicle ITS technologies. It is hoped that some of the lessons learnt from this project, and the findings that eventually derive from it, will help to provide an easier path for others who design and deploy ITS technologies designed to enhance the safety of car drivers.

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