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Considerations for the development of a driver distraction safety rating system for new vehicles

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Key Findings

- There is evidence that some vehicle cockpits are more demanding of drivers' attention, and have a higher potential to distract drivers, than others.
- It is predicted that a vehicle distraction safety rating system, when applied to the assessment of in-vehicle technologies other than mobile phones, has the potential to prevent three percent of all reported crashes.
- Three assessment methods are identified as being most suitable for incorporation into a vehicle distraction rating system: the Detection Response Task (DRT), the Visual Occlusion Test (VOT) and a Human-Machine Interface (HMI) design assessment checklist.
- A voluntary scheme to encourage vehicle manufacturers to produce less distracting in-vehicle technologies is the most feasible approach for introducing a distraction safety rating system in the short-term, with a longer-term vision of incorporating the test methods into established consumer rating systems such as New Car Assessment Programs (NCAPs).

Abstract

Drivers engage in a wide range of non-driving related tasks while driving that have potential to distract to them and compromise their safety. These include interactions with infotainment systems built into the vehicle by vehicle manufacturers. These systems enable the performance of communication, entertainment, navigation and internet browsing tasks. Performing these tasks can degrade driving performance and increase crash risk. Not all infotainment technologies in new vehicles are equal in terms of their potential to distract. This paper documents the findings of a study commissioned by the Victorian Department of Transport to determine the feasibility of developing a test protocol for rating the distraction potential of new vehicles entering the Australian market. A literature review, consultation with expert international researchers and industry representatives, and workshops, were conducted in order to determine those elements of the HMI design of infotainment systems that should be assessed, identify suitable candidate test methods for assessing the visual and cognitive load imposed on drivers when performing infotainment tasks, and derive options for a distraction rating system. In addition, safety/rating assessment program reviews and a cost-benefit analysis of introducing a distraction rating system were undertaken. Eight potential distraction test methods were discerned from the literature and consultation. It was concluded that the most suitable test protocol for a distraction rating system involves the use of an HMI design checklist in combination with measurement of the visual and cognitive load imposed on drivers when performing specific infotainment tasks, using the VOT and DRT, respectively. Eight options for introducing a distraction safety rating as a consumer or NCAP distraction rating are presented. Each option builds upon the previous, with the first option being the development of voluntary guidelines (where vehicle manufacturers work to these guidelines on a voluntary basis) to option eight, where NCAPs incorporate a distraction rating in the overall vehicle safety rating. The benefits of introducing a highly effective (best case) distraction rating system are estimated to result in a road crash saving of approximately AU$28 per 'improved/low distraction' vehicle per year.

Keywords

Driver distraction, workload, in-vehicle infotainment systems, rating, human factors, New Car Assessment Program (NCAP)

Glossary

Detection Response Task (DRT) – the DRT provides a measure of the level of cognitive load of a secondary task while driving, and an international standard has been developed by the ISO (International Organisation for Standardisation) for the standardisation of its use (ISO 17488).

Driving Activity Load Index (DALI) – is a tool for subjective evaluation of mental workload via self-report, purpose-developed for the driving context.

Human-machine interface (HMI) – a component of certain devices (in the vehicle; e.g. touch screens, buttons, dials) capable of handling human-machine interactions. The interface consists of hardware and software that allow driver inputs/tasks to be translated as signals for machines that, in turn, provide the required information and control to the driver.

Lane Change Test (LCT) – the LCT is a surrogate driving task for use in simulated driving studies that has been standardised (ISO 26022:2010).

NASA Task Load Index (NASA-TLX) – is a self-reported measure of workload divided into six subscales that measure mental demand, physical demand, temporal demand, performance, effort and frustration.

New Car Assessment Program (NCAP) – NCAP is a vehicle safety rating system that allows consumers to understand the safety level of vehicles based on crash tests and other safety assessments (with some NCAPs a star rating of zero to five is awarded to each vehicle, with five being the safest and zero the least safe). There are currently NCAPs in the USA, Europe, Asia and Latin America. The Australasian New Car Assessment Program (ANCAP) is an independent organisation with members from Australian and New Zealand.

Overall Workload Level (OWL) scale – is a self-report measure of workload gauged on a unidimensional scale from 0 (very low workload) to 100 (very high workload).

Secondary task – a non-driving-related task e.g., making phone calls, selecting music, using social media (e.g. via touching a visual display unit/infotainment system or using voice commands).

Visual Occlusion Test (VOT) – the VOT has been adapted to estimate the visual demand of a secondary activity. An international standard has been developed by ISO for the standardisation of its use (ISO 16673).

Introduction

Driver distraction is a significant road safety issue. Research suggests that it is a contributing factor in 16 percent of Australian crashes where a vehicle occupant is hospitalised (Beanland et al., 2013). Driver distraction is commonly defined as "...the diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving" (Regan, Hallett, & Gordon, 2011, p. 1776). Competing activities, according to this definition, can be driving or non-driving related. Drivers in Australia engage in a wide range of non-driving (secondary task) activities (Young et al., 2019). These include interactions with infotainment systems provided by vehicle manufacturers that allow for driver engagement in a wide range of communication, entertainment, navigation and internet browsing tasks. These interactions occur through a variety of technologies (e.g., screens built into dashboards, phone integration, head-up displays) controlled through touch, voice, gesture control and so on.

Performing infotainment tasks may distract drivers, resulting in delayed reaction times, poor lane keeping, increased eyes-off-road time and increased crash risk (Cunningham, Regan & Imberger, 2017).

Not all infotainment and other technologies, such as Advanced Driver Assistance Systems (ADAS) in new vehicles brought into Australia, are equal in terms of their potential to distract. The same technologies are often designed and implemented in very different ways across manufacturers. Research shows some vehicle cockpits are more demanding of drivers' attention, and therefore have higher potential for distraction, than others (Strayer et al., 2015; Strayer et al., 2017). Drivers often believe that if the HMI technology in the vehicle is provided, it has been deemed safe; however, this may not be so (Parnell et al., 2018).

Currently, there is no universally adopted method for assessing and rating, for any given vehicle, the level of distraction that may be created by driver interaction with in-vehicle infotainment systems. However, Strayer and colleagues from the University of Utah (2015; 2017) have developed a test protocol that is now being used to assess, rate and compare the distractibility of in-vehicle HMI interactions implemented in new vehicles. Methods investigated by Strayer et al. (2015; 2017) for inclusion in their test protocol assessing have included physiological measures (e.g. heart rate variability, eye movement/glances, brain waves (EEG)), self-report measures, such as the DALI and OWL, an HMI design check list and a measure of cognitive workload (the DRT).

Most new cars sold in Australia are tested under ANCAP, which now aligns with European NCAP safety protocols. The NCAP rating system has been highly successful in encouraging vehicle manufacturers to compete to produce safer vehicles (Paine & Regan, 2018). Incorporating into European NCAP or a similar rating program a distraction rating method, like that developed by the University of Utah, could be expected to encourage vehicle manufacturers to improve HMI design and produce less distracting vehicles. Incorporation of a distracting rating method in NCAP would also provide information to consumers regarding the distractibility of the in-vehicle infotainment system (or other systems, such as ADAS, if tested) in tested vehicles. At present no new vehicles are rated for their potential to distract drivers as part of any local or international NCAP programs.

The overall aim of this project was to determine the feasibility of developing an HMI distraction rating system, including its potential incorporation within Euro NCAP or another consumer information service. This research project involved extensive engagement and consultation with local and international stakeholders involved in NCAPs, driver distraction and road safety experts, as well as experts from the vehicle industry.

The study examined (a) how a safety rating system could be developed for assessing the level of distraction from in-vehicle technologies, and (b) how to develop and design a test protocol for rating the distraction potential of new vehicles in the Australian market. An in-vehicle HMI distraction rating system can support consumers to make safer purchasing choices, influence safer HMI design (for new vehicles, including Autonomous Vehicles [AVs]), and, possibly, development of future NCAP rating protocols. Options for introducing a consumer distraction rating system, and one suitable for incorporation into NCAP testing protocols, were also developed.

The exploratory study described in remaining sections of this paper was a first step in determining how to develop a distraction safety rating system and in determining how to implement it into new vehicles coming to market. Additional research, described later in the paper, will be required to further develop and refine a distraction safety rating system. The key outcomes of the study are reported here. More details of the methods, analyses and assumptions involved in deriving these outcomes can be found in the original reports documenting the outcomes of this research program (see Cunningham et al., 2017; Cunningham et al., 2018 a,b; Cunningham et al., 2018; Paine & Regan, 2018; Regan et al., 2018 and VicRoads, 2018).

Methods

The project had two components. Component One involved a major review of Human Factors and HMI guidelines, test methods, scoring criteria and other literature applicable to development of a Human Factors and Ergonomics star rating system - all with a focus on distraction from in-vehicle technologies. This enabled draft criteria to be identified for assessing safe Human Factors/ Ergonomics design, as well as test methods for assessing and rating the vehicle HMI against these criteria (Regan, Cunningham, & Paine, 2018).

Component Two involved the development of options outlining how a distraction rating system may be incorporated into existing vehicle safety ratings systems such as Euro NCAP; or how it could operate under an alternative regime. This component aimed to identify the most effective and feasible approach for introducing a distraction rating system and for estimating the potential crash savings from its implementation (Regan, Cunningham, & Paine, 2018).

Component One involved five main research tasks and associated sub-tasks. The tasks involved literature reviews, stakeholder consultations and use of the expertise held by the project team. The five main research tasks were as follows:

1. A review of the topics listed below. This involved a literature review, using transport and safety-related library search databases, google searches for grey literature, an ancestry approach, whereby the literature found was used to find further literature, and teleconferences and workshops with experts (more detail below) (Cunningham et al., 2017; Cunningham et al., 2018 a,b; Cunningham et al., 2018; Paine & Regan, 2018 and Regan et al., 2018):
    a. Types of distraction (visual, cognitive or bimanual interference [hands/feet off vehicle controls] caused by in-vehicle technologies and various interactions (e.g. touch screen, voice activation etc.), the driving performance decrements they cause and crash risks (if available) and links to poor or good HMI design, and any research gaps for developing an HMI distraction rating system. This information was distilled to create a distraction taxonomy that linked these items of information.
    b. Design and HMI components that enhance driver ease of use and safety that included solutions that mitigate distraction such as vehicle lock outs and workload managers.
    c. HMI guidelines and relevant best-practice Human Factors and Ergonomics principles (e.g. are HMI controls and their operation consistent with driver expectations, is information easily understood, are operational tasks remembered easily, etc.) and how they can be applied to an HMI distraction rating system.
    d. Criteria for assessing distracting activities and interactions with in-vehicle technologies, which included review of various HMI guidelines documents, e.g. those from the Japanese Automotive Manufacturer's Association, the Transport Research Laboratory (TRL) etc.
    e. Test methods used to assess distracting activities and interactions with in-vehicle technologies that included known ISO standards (e.g. for administering the DRT) and measures used to assess secondary task performance such as lane departure, reaction time etc.
    f. Any other issues and research gaps applicable to developing an HMI distraction rating system.
2. An assessment of HMI design attributes that should be rated and their basis (i.e. on a scale of one to five). The following issues were considered:
    a. how the attribute ratings (i.e. different functions/ technologies) should include the types of interaction used, e.g. making a phone call may occur via the use of dials, the touch screen and/or via voice command, resulting in three different ratings
    b. how different technologies may require different rating levels compared with others and how all ratings for a vehicle can be combined (i.e. into one score)

   c. rating technologies with more than one type of interaction, e.g. if voice commands were the safest to activate navigation, but other interactions were permitted, what is the final rating?
   d. quantifiable and reliable ratings.

5. Review of test methods for the HMI distraction rating system with an indication of their reliability and validity, and any barriers, risks and costs associated with use of them. Candidate test methods were rated against these criteria by the project advisory committee experts (see below).
6. Development of a potential HMI distraction rating system that considered practical issues for administration of the checklist, such as checklist rater qualifications, equipment and materials and scientific issues relating to administration of the VOT and DRT, such as the minimum duration of distracting (secondary) tasks necessary for measurement. A means of calculating a distraction rating score, by combining scores from the HMI design checklist, VOT and DRT, was also developed.
7. Future steps, potential costs and timeframes involved to develop a final HMI distraction star rating system were also considered.

Component Two involved six main research tasks and several associated sub-tasks, using literature reviews and consultation methods as per Component One. In addition, information was sourced from published protocols, consultations with selected NCAPs, presentations at recent Global NCAP meetings and the resources published by CARHS, a technical training organisation based in Germany (safetywissen.com). The main tasks were (Regan, Cunningham, & Paine, 2018b; Cunningham et al., 2017):

1. Outline how the current NCAP star ratings operate, important change processes/approvals required, components and barriers/issues to changing NCAP protocols (including Australasian NCAP, Euro NCAP and US NCAP).
2. Determine which government, industry and vehicle manufacturing stakeholders, worldwide, that are essential for participation in, and advocacy for, developing a distraction safety rating now and in the future; e.g., Australian NCAP, European NCAP, US NCAP, road authorities, insurers, vehicle manufacturers, other industries and academia.
3. Determine each stakeholder's role, including ongoing support; potential financial or in-kind contribution; importance and degree of influence and any other functions for developing and providing an ongoing distraction rating.
4. Document how to include an HMI distraction rating in Euro NCAP assessments (including requirements that cover the distraction rating as part of an overall NCAP score or a separate standalone rating) or for alternative methods that will have an impact on vehicle manufacturers and consumer behaviour. Component Two resulted in eight options for introducing a distraction safety rating system, with each option building upon the previous in terms of being able to achieve the desired outcomes, particularly in terms of the uptake of improved HMI design.
5. Document barriers, risks, benefits and disbenefits, future steps and research requirements, costs, advocacy levers and timeframes for different methods of introducing an HMI distraction rating system.

The project was supported by ANCAP and Euro NCAP through in-kind support. Consultation was undertaken with these NCAPs for Component Two of the project and both stakeholders were on the project advisory Committees (described below). At the beginning of the project the project team organised and ran a special session on this project at the 5th International Conference on Driver Distraction and Inattention (held in Paris, France; April 2017). The outcomes of this session provided a basis for identifying key issues requiring consideration throughout the project, especially in relation to the suitability of possible distraction test methods. Scientific and Ratings Advisory Committees (for Components One and Two of the project, respectively), consisting of local and international experts, were established to provide project guidance (Table 1). The Scientific Advisory Committee, chaired by the Department of Transport, comprised local and international driver distraction and HMI design experts. The Ratings Advisory Committee, chaired by ANCAP, comprised representatives from local and international vehicle safety rating organisations, including NCAPs. Committee members provided in-kind support via teleconferences, ad hoc advice and peer review of select deliverables.

During Component One of the project, the project team engaged closely with two distraction experts from the University of Utah who had undertaken related work sponsored by the American Automobile Association Foundation for Traffic Safety (AAAFTS; USA). This involved a week-long workshop in Melbourne and ad-hoc communication as required (and through the Scientific Advisory Committee). The AAAFTS has recently published in-vehicle distraction safety ratings for over 40 vehicles produced by the University of Utah (AAA Exchange, 2017).

Results and discussion

Key outcomes of the project are reported here. Further details can be found in the original reports documenting the outcomes of this research program (see Cunningham et al., 2017; Cunningham et al., 2018 a,b; Cunningham et al., 2018; Paine & Regan, 2018; Regan et al., 2018; VicRoads, 2018).

Distraction testing methods

The literature review and expert consultations identified eight potential methods by which the distraction potential of the HMI for vehicle infotainment system interactions might be evaluated for rating purposes. These methods, along with

Table 1. Scientific and Ratings Committees experts

Expert	Organisation	Country
Scientific Advisory Committee		
Dr Linda Angell	Touchstone Evaluations	USA
Prof Klaus Bengler	University of Munich	Germany
Dr Marie-Pierre Bruyas	IFSTTAR	France
Prof Gary Burnett	University of Nottingham	UK
Dr Peter Burns	Transport Canada	Canada
Prof Oliver Carsten	Leeds University	UK
Dr Maria Beatriz Delgado	IADIA/Euro NCAP	Spain
Dr Johan Engstrom	Virginia Tech/Volvo Cars	Sweden
Emeritus Prof Don Fisher	Volpe Institute	USA
Dr Joanne Harbluck	Transport Canada	Canada
Dr William Horrey	AAA Foundation for Traffic Safety	USA
Adj. Prof Michael Lenné	Seeing Machines	Australia
Adj. Prof Alan Stevens	(ex) Transport Research Laboratory	UK
Dr Ingrid Skogsmo	Swedish National Road and Transport Research Institute	Sweden
Adj. Professor Trent Victor	Volvo Cars	Sweden
Dr Kristie Young	Monash University	Australia
Ratings Advisory Committee		
Matthew Avery	Thatcham Research	UK
David Beck	Transport for NSW	Australia
Mark Borlace	Royal Automobile Association	Australia
Andrew Dankers	Department of Infrastructure and Regional Development	Australia
Dr David Kidd	US Insurance Institute for Highway Safety	USA
Robert McDonald	IAG Insurance	Australia
Peter Martin	National Highway Traffic Safety Administration, US	USA
Richard Schram	Euro NCAP	Belgium
Mark Terrell	Australian New Car Assessment Program	Australia
Andre Wiggerich	BASt, Germany	Germany
Dr David Yang	AAA Foundation for Traffic Safety	USA

their identified advantages and disadvantages, are contained in Table 2 below (Cunningham, Regan & Imants, 2018b).

HMI assessment method(s) need to be sensitive enough to reliably discriminate, from a distraction perspective, between good and poorly designed HMIs. This is a critical scientific consideration. Distraction may induce one or more of the following "triggered behavioural responses": eyes off road, mind off road and hand(s) off the steering wheel (Regan, Hallett, & Gordon, 2011). Therefore, to adequately assess the level of distraction produced through an HMI and the tasks it supports, assessment method(s) are needed that tap into each of these components of distraction (Cunningham, Regan & Imants, 2018).

Table 2. Candidate HMI assessment methods for use in distraction rating system

HMI assessment method and description	Advantages and disadvantages
<u>1. Checklist – HMI design</u> A suitably qualified assessor rates the physical and software design attributes of the HMI using a checklist containing design criteria against which the distraction potential of the HMI design is assessed. Undertaken whilst the vehicle is stationary.	Advantages: • quick to administer, cheap, no participants required • minimal equipment – checklist and pen/paper or tablet computer • many physical and software HMI design attributes can be assessed, particularly key attributes leading to distraction • taps into all three distraction types (visual, cognitive and auditory), with design guidelines and principles that derive predominantly from established human factors theory and principles – a draft checklist was developed by the project team as part of this project. • Disadvantages: • no known validated distraction assessment checklists exist • very little guidance available on checklist assessor qualifications required for administration • lack of empirical evidence that 'optimal HMI design based on adherence to a set of design guidelines/checklists reduces crash risk • does not involve driving.
<u>2. Checklist – interference potential</u> Similar to Method 1. A suitably qualified assessor rates the HMI for distraction interference potential using a checklist. However, the focus is not on rating the physical and software design attributes of the HMI itself. Rather, the assessor rates the interference potential of the secondary tasks (e.g. interacting with the infotainment system to change music, instigate navigation or make a phone call) that are to be performed using the HMI while driving.	Advantages: • quick to administer, cheap, no participants required • minimal equipment – checklist pen/paper or tablet computer • detail on distraction potential of secondary tasks (Method 1 does not achieve this). • Disadvantages: • similar to Method 1
<u>3. Simulator or real vehicle to assess distraction</u> An experimenter measures the impact of distraction on driving performance. Normally involves a driving simulator, instrumented vehicle or surrogate driving task that mimics some part of the driving task (e.g. Lane Change Test). A tester and participant are required. Involves a comparison between driving performance in a baseline condition (undistracted driving) and a distracted condition (in which the test subject performs a secondary task through the HMI).	Advantages: • direct measure of impact of distraction on driving performance • extraneous variables (e.g. road type, weather) can be easily controlled • safe driving environment. • Disadvantages: • may be unsafe to assess distraction on real roads • simulator sickness for some participants • difficult/costly to reproduce different HMI designs for a simulator • simulation often doesn't allow self-regulation of driver engagement in secondary tasks as in real-world driving.

HMI assessment method and description	**Advantages and disadvantages**
4. Expert rater to assess distraction using a checklist Similar to Method 3 but requires tester to rate driving performance using a checklist (like the Vienna Fahrprobe checklist used in Europe to rate driving performance for progression to solo driving), using a simulator or real vehicle. This method does not currently exist. If it did, it would require a suitably qualified assessor and a participant. It would involve a comparison of ratings of driving performance between a baseline condition (undistracted driving) and a distracted condition (in which the participant engages with a secondary task(s) while being rated).	Advantages: • assessment tool available. Disadvantages: • not time efficient - at least a week needed to collect enough data to assess each vehicle • may not discriminate between visual and cognitive distraction • traffic situations in current version of Vienna Fahrprobe would need to be updated.
5. Surrogate assessment tasks to measure cognitive and visual load Involves the use of a surrogate assessment task to measure and rate the degree of cognitive load (e.g. using the DRT) or visual load (e.g. using the VOT) imposed by the performance of a secondary task. Unlike Method 3, it does not measure changes in driving performance due to a driver interaction. Rather, it measures the *load* imposed by a secondary task (cognitive load for the DRT, and visual load for the VOT, which may then be used to make an inference regarding the level of interference [distraction] between the secondary task and activities critical for safe driving). It requires an assessor and a participant and surrogate assessment tasks can be performed in a simulator or real vehicle.	Advantages: • standards defining procedures for administering some surrogate assessment tasks have been developed by ISO (e.g. for VOT and DRT) • inexpensive, easy to use • can validly discriminate between tasks for visual and cognitive demand. Disadvantages: • VOT - doesn't show how a task affects the return of driver gaze to the forward roadway; presentation rate of occlusion/unoccluded events is predictable • DRT - test is time consuming - takes around three weeks per vehicle for data collection (N=24) and duration of secondary tasks needs to be at least five seconds long as DRT stimulus is presented every two to three seconds.
6. Measure perceived (self-reported) workload Involves the collection of self-reported ratings of workload (associated with a secondary task) from participants after a drive. Workload ratings may be compared between a baseline condition (undistracted driving) and a distracted condition (in which the test subject engages with a secondary task[s] while being rated). Alternatively, workload ratings may be compared between different secondary tasks. Three questionnaires are commonly used: the National Aeronautics and Space Administration Task Load Index (NASA-TLX), the Driving Activity Load Index (DALI) and the Overall Workload Level (OWL) scale.	Advantages: • easy and cheap to administer in conjunction with other assessment methods • can easily compare ratings across different tasks • participants are particularly good and robust at self-rating the visual and cognitive load they experience when undertaking a certain task. Disadvantages: • difficult to determine if participants reporting overall workload levels averaged over the entire testing period or to specific peaks in workload • ratings lack objectivity, so less acceptable for rating regimes (e.g. NCAPs).

HMI assessment method and description	Advantages and disadvantages
7. Measure driver psycho-physiological characteristics An experimenter assesses the secondary task in terms of the degree to which it elicits psycho-physiological responses in the driver which are known to be correlated with increases or decreases in visual and cognitive load (e.g. heart rate variability, eye movement/glances, pupil dilation, brain waves (EEG)). Requires a tester and participant.	Advantages: • Eye glance metrics are consistently reported to be among the best performing diagnostic metrics for measuring distraction and workload and have good predictive validity with respect to crashes (e.g. two seconds eyes off road doubles crash risk). Disadvantages: • not entirely reliable e.g. other factors can influence these signals (related to a driver's reaction to physical exertion, emotional state or ambient lighting) – occasionally leading to unclear conclusions • complex technology required • can be intrusive • need multiple measurement indexes • very expensive.
8. Analytical modelling This method involves an analysis and modelling of the tasks a driver would perform when interacting with an in-vehicle device/function and prediction of the level of distraction produced from those interactions. The aim is to break the task down into its fundamental components to understand the characteristics that will increase distraction (e.g. visual demand for an in-vehicle touchscreen will increase with a greater distance between an on-screen 'button' and the steering wheel, or when there are more buttons on the touchscreen, etc.). This method does not require a test driver to conduct the assessment. However, an experienced analyst is required to develop the predictive model.	Advantages: • practical, very quick to undertake and subsequently extremely cost-beneficial • identifies HMI tasks that are particularly distracting so can prioritise tasks for further assessment through user trials • can be applied much earlier in HMI design process, as a working HMI prototype is not required compared with other assessment methods. • Disadvantages: • predicts the distraction potential for a given task as opposed to measuring distraction directly • can currently only be applied to simplistic in-vehicle tasks using HMI touchscreens (e.g. entering destination on in-vehicle navigation system) • not yet refined enough to assess voice input tasks.

The number of experts on the Scientific Advisory Committee (13 in total) who definitively endorsed the suitability of each HMI assessment method for the purposes of this study (ranked from most to least endorsed), based on these and other relevant considerations, was as follows (Cunningham, Regan & Imants, 2018):

- Method 1: HMI design checklist – eight experts
- Method 5(a): Surrogate driving task (DRT) – six experts
- Method 5(b): Surrogate driving task (VOT) – six experts
- Method 8: Analytical modelling – six experts
- Method 3: Simulation – three experts
- Method 6: Self-reported workload – three experts
- Method 4: Test drive with expert rater – one expert
- Method 7: Physiological measures – no experts endorsed its use
- Method 2: Interference potential of secondary task checklist – no experts endorsed its use.

Overall, the international experts recommended HMI assessment Method 1 (checklist), Method 5(a) (DRT) and 5(b) (VOT) as the three most suitable for the purposes of this project. While Method 8 (analytical modelling) was also highly endorsed, it was not regarded as being sufficiently mature enough for use when investigated. This combination of endorsed methods is therefore recommended for inclusion in a distraction rating system (Cunningham, Regan & Imants, 2018).

The DRT is an internationally recognised and validated measure of cognitive demand (ISO 17488:2016; (ISO, 2016)). The VOT is, similarly, an internationally recognised and validated measure of visual demand (ISO 16673:2017 (ISO, 2017)). Both measures are used by many vehicle manufacturers early in the in-vehicle HMI design process. The checklist, developed by the project team, derives from several well-established vehicle HMI design guidelines and standards (VicRoads, 2018). The checklist can tap into visual and cognitive distraction and bi-manual interference, with design guidelines and principles that derive predominantly from established human factors theory and principles (e.g. NHTSA, 2013). Together, these three methods were judged by the project team, and the international experts, as being capable of being combined to measure and rate the potential for distraction deriving from driver interactions with in-vehicle infotainment systems (Regan, Cunningham, & Paine, 2018).

Options for introducing a distraction rating system

In terms of introducing a distraction rating system, the following schemes were identified and listed in a hierarchy. The hierarchy, going from Option 1 to Option 8, represents the least favourable to most favourable, respectively, in terms of likely effectiveness (e.g. uptake of improved HMI in new vehicles). In general, schemes with less oversight are likely to cost less and be easier to implement but are less effective at changing the vehicle fleet. A staged approach could fast-track introduction of improved HMI designs in the short term and allow incorporation in NCAP (or other) rating systems in the longer term. The hierarchy of possible rating systems is outlined below, together with page references to Regan, Cunningham, and Paine (2018).

Option 1 - Voluntary guidelines

"Guidelines for HMI design and testing are published by a suitably recognised organisation (e.g. ISO) and vehicle manufacturers work to these guidelines on a voluntary basis, possibly through a memorandum of understanding with NCAPs/regulators" (page 35).

Option 2 - Voluntary standards with self-certification

"Standards are published by a relevant organisation, such as an NCAP or a standards association. The vehicle manufacturer designs the HMI to these standards and states that the vehicle meets the guidelines. Consumer law discourages vehicle manufacturers from making false claims but there is no formal auditing/enforcement. This avoids the cost and difficulties of a formal certification system" (page 36).

Option 3 - Voluntary standards with independent certification

"Standards are published. Vehicle manufacturers arrange third party certification to these standards. This method is used for safety products such as child restraints and bicycle helmets" (page 36).

Option 4 - Voluntary protocols with recognition by NCAP

"Test protocols are developed, and vehicle manufacturers work to these protocols. Vehicle manufacturers approach an NCAP and seek acknowledgement that they have designed the vehicle to the guidelines. This is like the Euro NCAP 'Advanced Rewards'. The NCAP does not publish a rating in these cases but simply acknowledges that the vehicle manufacturer has designed the vehicle to the agreed protocol" (page 36).

Option 5 - Voluntary rating with auditing by NCAP

"Vehicle manufacturers submit test results to the NCAP for the full range of tests set out in an HMI/distraction protocol. The NCAP conducts a random selection of tests as an audit of the vehicle manufacturer submission. Scores are adjusted if the audit finds significant discrepancies. The NCAP publishes distraction ratings, where available" (page 36).

Option 6 - Mandatory rating with auditing by NCAP

"The NCAP publishes a distraction rating for all new safety ratings using Option 5. Vehicle manufacturers who chose to not submit test data for Option 5 above could still receive a distraction rating, but it would default to 'poor'. However, a checklist approach could be utilised to give the vehicle manufacturer the options of improving this default (to say 'marginal')" (page 36).

Option 7 - Mandatory independent rating with all tests conducted by NCAP

"The NCAP conducts the full suite of tests - that is, measuring/testing done in laboratories with no vehicle manufacturer data" (page 36).

Option 8 - Distraction rating incorporated in overall safety rating

"The NCAP incorporates a distraction rating in the overall safety rating, using the same procedures as Options 5 or 7. This option could be implemented if the above options do not result in a reasonable improvement in HMI across the fleet" (page 36).

Options 1 to 4 are pass/fail systems where the HMI design meets (or does not meet) agreed minimum requirements, similar to the way in which regulations operate. Options 5 to 8 have an independent organisation scoring/rating the HMI system. The options were assessed using the Strategic Merit Test methodology (Rose & Richardson 2010) that rates the likely effect of each option on a range of desired outcomes related to safety and a sustainable framework (details of this analysis can be found in Regan, Cunningham, & Paine, 2018). Based on this analysis, the following three options are considered viable options for consideration by rating organisations such as NCAPs:

- Option 5 – Voluntary rating with auditing by an independent rating organisation
- Option 6 – Mandatory rating with auditing by an independent rating organisation
- Option 7 – Mandatory independent rating with all tests conducted by the independent rating organisation.

All of these options involve the development of a test and assessment protocol that results in a scaled (e.g. 'poor' to 'good') distraction rating. This is expected to have better safety outcomes than guidelines or a simple pass/fail system such as in Options 1 to 4. This is because a simple pass/fail system provides no incentive for manufacturers to achieve performance that is much better than the minimum pass level. This was evident in early results of NCAP crash tests where it was found that many vehicles barely passed the equivalent regulation requirements, but some vehicles did much better at protecting occupants. The NCAP system is designed to reward better performance and discourage consumers from buying the least safe vehicles.

The difference between the three recommended options is the degree to which vehicle manufacturers and rating organisations conduct tests, as well as the level of scrutiny applied to the assessment of distraction from the in-vehicle HMI. Recently Euro NCAP and Australasian NCAP have moved towards the audit of test results submitted by manufacturers (this "grid method" is used for pedestrian protection tests, autonomous emergency braking tests and lane support system tests) and is similar to Option 5 (voluntary rating with auditing by an independent rating organisation) discussed above. This is considered viable for a distraction rating system and would substantially reduce operating costs for the rating organisation (manufacturers would need to conduct all the tests if they wished to achieve good ratings). Obviously, Option 8 would be the most effective option, but would pose additional costs for NCAPs.

It should be noted that the introduction of improved HMI design to reduce distraction through mandatory regulation was not considered by the project Ratings Advisory Committee to be a viable option due to the constraints of international harmonisation.

Benefits and costs from a distraction rating system

The potential benefits and costs of a distraction rating system were analysed, but it is important to remember that the actual benefits of any implementation option will depend on many factors, including the proportion of the vehicle fleet that has improved HMI design to reduce distraction (and its uptake by consumers). Experience with other NCAP initiatives is that it typically takes several years for more than 50% of new models to perform well in a particular area. National fleet penetration is slow, so it takes many more years before most vehicles in use have a particular safety performance level (Regan, Cunningham, & Paine, 2018).

Due to these uncertainties, the benefits and costs of various implementation options have not been estimated at this stage. Instead, a range of estimated cost benefits is provided. The benefits and costs analyses showed (Paine & Regan, 2018):

- *Potential crash savings through improved HMI to reduce driver distraction.* It is estimated that the proposed distraction rating system (using the checklist, DRT and VOT), when applied to in-vehicle technologies other than mobile phones, has the potential to prevent 3% of all reported crashes. This is based on the Dingus et al. (2016) analysis of 905 US non-fatal crashes where naturalistic driving data were available. In brief, 6% of crashes would likely have been avoided if the driver had not been distracted by one of the non-phone technologies. Members of the Scientific Expert Group estimated that, with 100% effectiveness, improved HMI would have saved half of these cases, giving an overall saving of 3%.
- *Cost of road crashes in Australia.* Dividing the estimated costs of road crashes in Australia in 2006 (Bureau of Infrastructure, Transport and Regional Economics report 'Cost of Road Crashes in Australia 2006') by the number of registered motor vehicles in that year gives an annual crash cost per registered vehicle of AU$1,166. Costs will have increased since that time and so any analysis based on 2006 data will be conservative (data beyond this date was not available for analysis).
- *Effectiveness of a rating system.* It was estimated that the potential effectiveness of a distraction rating system ranged from 20% to 80% depending on the success of the system in encouraging improved HMI. This translates to crash reductions of 0.6% to 2.4% respectively (3% x 20% = 0.6%, 3% x 80% = 2.4%). Assuming that a highly effective distraction rating system (80% effectiveness) reduces all types of crashes by 2.4%, then the annual saving is estimated to be AUD$28 per 'improved' vehicle (2.4% of AUD$1,166). A distraction rating system with low effectiveness (20%) is estimated to result in an annual saving of AUD$7 per 'improved' vehicle (0.6% of AU$1,166).
- *Increased cost of new vehicles.* Subject to many factors, it is estimated that the typical incremental cost of producing a vehicle with good HMI design will increase by AUD$20. Amortised over 5 years, this is about AU$5 per year. Therefore, a distraction rating system with low effectiveness will be barely cost-effective (net saving AUD$7-$5=$2 per vehicle per year). A high-effectiveness system is estimated to save about AUD$23 per vehicle per year (AUD$28-$5=$23).
- *Cost of implementing and operating a rating system.* Details of the rating system are yet to be finalised, so there is considerable uncertainty about costs of implementing such a system. Based on experience with other rating systems, estimated implementation costs (for administration, contractors to manage the implementation of the scheme, test equipment acquisition and set-up and marketing) totals AUD$300,000. Estimated annual costs, again with uncertainty (for administration, contractor overheads, testing overheads, marketing and testing of 20 vehicles per year [assuming the rating organisation conducts all tests]) totals AUD$500,000.
- *Benefit-cost analysis.* The benefit/cost analysis indicates that a distraction rating system will break-even after five years given relatively few vehicles with improved HMI entering the fleet each year - for the analysed baseline parameters about 8,483 new vehicles per year or 0.84% of new vehicle sales in Australia. For a higher benefit/cost ratio, as is usually required for justifying regulatory action, more new vehicles will need to have improved HMI. For example, for

the base case that assumes a median annual cost of AUD$550,000, AUD$5/vehicle/year and 7% discount, increasing the number of new vehicles with improved HMI from 8,483 (0.84%) to 16,967 (1.68%) produces a benefit/cost ratio of 2.

- *The benefit-cost analysis was confined to implementation in Australia.* Any improved HMI design resulting from this scheme is likely to influence vehicle HMI design in other regions, particularly if a globally-recognised rating system is implemented. The economies of scale can be expected to produce lower costs and therefore a better benefit/cost ratio than the analysed case.

Conclusions

There is evidence that distraction from in-vehicle infotainment technologies may degrade driving performance and safety. Therefore, it is important to influence vehicle manufacturers to design the in-vehicle HMI in a way that minimises distraction from these systems. Developing a distraction rating system is an important step to make this happen and improve vehicle safety for consumers.

Driver distraction from in-vehicle technologies, generally, has the potential to degrade multiple psychophysiological processes and therefore no single test can comprehensively evaluate distraction potential. The findings from this study suggest three assessment methods that, in combination, are most suitable for assessing the distraction potential of in-vehicle technologies– the DRT and VOT that measure cognitive and visual load, respectively, and an HMI design checklist. The results of these assessment methods can be used to create a distraction rating system for vehicle cockpit testing.

Once distraction ratings become available through conducting these tests on vehicles in Australia, a voluntary scheme (with auditing by an independent rating organisation) for encouraging vehicle manufacturers to produce less distracting vehicle HMIs is considered the most feasible approach to implementing a rating system in the short-term, with a longer-term vision of incorporating the test method into consumer rating systems such as NCAP. The type of vehicle buyer that could be the initial target of a consumer distraction rating system is likely to be company fleets. An alternative option to establishing a consumer rating is to seek the development of a UN Vehicle Regulation to address HMI-related distraction issues in new vehicles but this would likely mean several years of delay in seeing the benefits of improved HMI design, assuming the proposal proceeds to international regulation.

It is concluded that this area of driver distraction requires a dedicated and innovative ongoing international research effort. An HMI distraction rating system that is credible to industry and consumers is feasible but requires further validation and possibly demonstration of its potential to reduce crashes - similar to evidence requirements directing the policies of NCAPs.

The ability to undertake a proof-of-concept study that will employ the distraction safety rating system described in this paper to rate the distraction potential of a small number of new Australian vehicles is currently being investigated. This study is required to determine the efficacy of the proposed distraction testing protocol (HMI checklist (which requires development), DRT and VOT) and if a distraction rating can be computed. The distraction rating computations will be based on the outcomes of the proof-of-concept study and the distraction rating method developed by Strayer and colleagues (2015; 2017) with the additional inclusion of the VOT. The aims of the study are to:

- develop an extended distraction rating method for use in Australian conditions
- build Australian domestic capability for conducting assessment of the distractibility of HMIs in vehicles
- establish the basis for a wider-scale project to test additional vehicles that will ultimately lead to improved designs of future vehicle HMIs to reduce distraction and crash risk.

If the proof-of-concept study can be undertaken and proves successful, a much larger study with a large range of vehicles available for distraction assessment will need to be undertaken. To continue to rate new vehicles coming to market for their distraction potential ongoing funding would be required. This would ideally be undertaken by an independent rating organisation who would source such funding.

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