# Methodology to assess safety effects of future Intelligent Transport Systems on railway level crossings

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## Abstract

There is consistent evidence showing that driver behaviour contributes to crashes and near miss incidents at railway level crossings (RLXs). The development of emerging Vehicle-to-Vehicle and Vehicle-to-Infrastructure technologies is a highly promising approach to improve RLX safety. To date, research has not evaluated comprehensively the potential effects of such technologies on driving behaviour at RLXs. This paper presents an on-going research programme assessing the impacts of such new technologies on human factors and drivers' situational awareness at RLX. Additionally, requirements for the design of such promising technologies and ways to display safety information to drivers were systematically reviewed. Finally, a methodology which comprehensively assesses the effects of in-vehicle and road-based interventions warning the driver of incoming trains at RLXs is discussed, with a focus on both benefits and potential negative behavioural adaptations. The methodology is designed for implementation in a driving simulator and covers compliance, control of the vehicle, distraction, mental workload and drivers' acceptance. This study has the potential to provide a broad understanding of the effects of deploying new in-vehicle and road-based technologies at RLXs and hence inform policy makers on safety improvements planning for RLX.

**Keywords:** Railway Level Crossings; Intelligent Transport Systems; Human Machine Interface

## 1. Introduction

Crashes at railway level crossings (RLXs) in Australia between 2001 and 2008 resulted in 342 fatalities (43 each year on average), 605 collisions (76 each year on average) and $32 million in costs each year (Australian Transport Safety Bureau, 2010). Collisions at actively protected crossings account for two-thirds of all costs (Cairney, 2003), suggesting that there is a need to improve safety at both actively and passively protected level crossings.

Vehicle-related and environment-related factors are not commonly used to provide explanation for a level crossing collision in isolation of driver-related factors. Driver-related factors are involved in most collisions at level crossings. These factors are mainly a result of driver errors rather than driver impairment. More specifically, unintentional errors are more common than intentional violations: failure to detect the crossing and/or the train, and misjudgements regarding the approaching train's speed and distance (Abraham et al., 1998, Australian Transport Safety Bureau, 2002).

The most severe crashes at RLXs are often due to driver misjudgements of the amount of free space available after the crossing. In high traffic, one vehicle can trap another vehicle on the crossing. However, the blocking back issue can only occur when there is sufficient traffic to cause a queue. This issue is therefore irrelevant to passive crossings, which are characterised by low traffic volumes. Blocking back is a contributing factor to crashes at RLXs, as drivers may make the decision to cross when the signal is not activated although there is no space available to complete the crossing. It has been observed in the UK that a third of the driver population is likely to trap the vehicle in front on the crossing. Moreover, such a situation is quite frequent and not confined to offenders (McKenzie-Kerr et al., 2011).

Both age and familiarity with the railway crossing have also been found to influence the risk associated with driving on RLXs. Recent research suggests that drivers aged 60 years and over have impairments that can directly affect their driving at RLXs such as difficulties adjusting to glare and night-time driving, restricted range of motion to the neck and substantial declines in hearing (Wallace, 2008). A further problem among older drivers is the association between familiarity and unsafe driving practices. Research suggests that many older drivers are unaware that what would normally constitute a risky driving situation (such as a complex intersection) has become specifically risky for them (Holland and Rabbitt, 1992). Given that older people constitute the fastest growing sector of the driving population, and that they exhibit a higher crash rate per distance travelled, this group requires particular attention.

Novice drivers (aged 17-24 years) are another group that requires specific attention at RLXs. Recent research indicates that young drivers, particularly males, have low levels of self-efficacy when it comes to driving at level crossings. Self-efficacy relates to individual's capacity to organise, control and execute certain behaviours to attain specific performances (Sheeran et al., 2003). It relies on the accuracy of an individual's perception of their control of the behaviour. With Wallace's (2008) study indicating low levels of self-efficacy among younger drivers at RLXs and the results from research suggesting that a high level of self-efficacy is required to obtain greater success of behavioural change (Wells-Parker et al., 2000), it appears that younger drivers, especially males and those with low-self efficacy, are particularly in need of the use of infrastructure or warning systems, where possible, as educational interventions are likely to have a low rate of success.

It has been reported in an Australian survey that 20% of 4,400 drivers had become aware of a RLX only after they had crossed it (Sochon, 2008). It is important that the road user detects the presence of the crossing early enough in order to define and implement a strategy for safely approaching and crossing the railway. New Intelligent Transport Systems (ITS) can help to increase driver awareness as they approach RLXs. Such systems should only be used when trains are arriving at a RLX, as otherwise they could irritate drivers with numerous warning signals, even when no risk of collision is present. This issue is even worse for drivers who cross a particular crossing regularly. Therefore this project focuses on assessing the effects of such new ITS to increase drivers' awareness as they approach RLXs. The aim is to evaluate driver compliance as well as driver acceptance and perceived usefulness of new technologies when approaching RLXs. Drivers' errors at RLXs underscore the importance of making the crossing salient, and therefore this paper will first introduce the requirements of new ITS interventions for improving driver awareness around crossings. Emerging technologies are then reviewed in order to highlight the potential for new interventions at RLXs. Such interventions need to follow good practice in terms of human factors, particularly Human Machine Interface (HMI), and this is discussed in the following section. Finally, a methodology to assess the effects such interventions is provided. This methodology focuses on evaluating compliance, control of vehicle, distraction and driver acceptance of the technology.

## 2. Requirements for improving awareness around RLXs

The National Road Safety Action Plan 2009 and 2010 affirms that Australian State and Territory governments have adopted a safe systems approach as a core measure to improve road safety, while the Draft Rail Safety National Law 2011 attempts to harmonise rail safety in all States of Australia. The approach recognises that collective responsibilities of different parties are needed to effectively improve road safety, including infrastructure providers, infrastructure managers, transport regulators and road users. The stakeholders to consider for improving the specific issue of safety at RLXs are rail regulators, rail industry and operators and road users. Each of them has different needs and expectations in regards to the development of ITS interventions, which are presented in the following sections.

### 2.1. Rail Regulators

The National Railway Level Crossing Safety Strategy 2010-2020 describes approaches for improving the safety of Australia's land transport system. Rail regulators aim to reduce the number of crashes and associated costs at RLXs. With more than 1500 passive crossings throughout Queensland alone, and given that collisions are distributed across thousands of RLXs throughout the national network, it is difficult to justify the installation of expensive active protection systems which have a low likelihood of a collision. Alternatively, there are affordable solutions, such as ITS interventions, that can be used to reduce driver errors. These interventions may not only save lives but also be much more beneficial financially by avoiding major infrastructure damage, environmental disaster, and potential delays in the rail network. Potential undesirable consequences of new technologies should also be investigated during the development stage. Hence the proposed methodology of this project will evaluate whether reducing the difficulty of driving through a RLX with ITS technology will result in a reduction of driver errors, while consideration will also be given to the potential negative behavioural that may arise.

### 2.2. Rail Industry and Operators

The responsibility for rail safety in Australia is shared by the government and rail industry under a co-regulatory approach. Industry is “responsible for addressing risks to safety by identifying and implementing the most effective and efficient solutions via their safety management systems, and achieving required safety outcomes" (Australian Transport Safety Bureau, 2010). The needs of rail industry and operators have been investigated though consultations with the following rail industry bodies and operators: Queensland Rail, Queensland Transport, Department of Transport and Main Roads, VicTrack, Australian Rail Track Corporation (ARTC), Rail Industry Safety and Standards Board. ARTC estimates that the costs associated with improving a level crossing should be no more than $50k in order to be financially sustainable. This estimation takes into account the fact that there is a limited budget to upgrade the large number of passively protected level crossings in Australia. Currently, potential low-cost train detection systems range from $100k to $150k.

### 2.3. Road Users

Driver errors are the main contributing factor to crashes at RLXs. Driver errors are mainly due to failure in detecting the crossing, failure to detect the train (e.g., due to complacency), and misjudgement regarding the speed and distance of an approaching train. Drivers need assistive information that will increase their situational awareness. This enables them to perceive, understand, and accurately foresee forthcoming dangerous situations with enough time to safely avoid these situations. Compliance would be attained only if there are high levels of driver acceptability of railway level crossing warning devices. Compliance is largely contingent on the perceived credibility of the warning device, and perceived credibility requires a highly reliable device. Therefore ITS interventions must be designed to avoid over-reliance (drivers still need to check for trains) and the message conveyed to drivers must follow principles that safeguard against mental overload and distraction.

## 3. Emergent technologies

A range of new and affordable technologies are rapidly emerging and these represent a potentially effective approach to improving driver detection of RLXs and trains. A number of technologies are currently being implemented or trialled for the purposes of RLX safety, including: in-vehicle warning systems (e.g. collision avoidance systems), dynamic warning signals (e.g. advanced variable message warning signs and second-train warning signals), automated photo and video enforcement, obstacle detection systems and alternative low-cost train detection systems. In-vehicle warning messages and supplementary road-based warning signals have the potential to provide information about the crossing and approaching trains and hence are likely to improve driver awareness at crossings.

The evolution of ITS may complement or replace current RLX systems. Integrated Vehicle Based Safety Systems and Dedicated Short Range Communication systems, for example, are beginning to appear in new vehicles and, when coupled to Communication based Train Control systems and enhanced Driver Vehicles Interfaces, would place the level crossing protection system inside the vehicle rather than on the wayside. While it will likely take several decades for this to be fully realised, there is a high probability that any new level crossing protection system will not enjoy the lifespan of its predecessors.

Many railways currently face the challenge of providing better and safer RLXs while maintaining affordable operational costs. Using wireless technologies is a cost-effective solution likely to allow deployment of new interventions without having to invest in costly cables. Wireless communications have recently been considered by the rail industry as generally able to perform multiple functions, such as monitoring, traffic control and vital information such as signalling (SELCAT, 2008).

Considering possibilities of data transmission, two different classes of communication can be found. The first class corresponds to a communication using devices which already exist or are planned to be implemented, such as the 2.5G General Packet Radio Service (GPRS) (Michel and Ramasarma, 2005). The second class concerns signals sent to moving devices and which require the introduction of new solutions. For example, some dynamic information of the control centre may be sent onto the road user's GPS reception device.

In-vehicle warning devices are the only viable ITS intervention at crossings that cannot be upgraded (due to cost), given that the only way for the system to provide dynamic information regarding the train would be to send a message to the vehicle. The most affordable solution is for trains to send the signal and communicate directly with cars close to the RLX, as this would avoid the high cost of upgrading passive RLXs to active ones, given that there are fewer trains than there are level crossings. The deployment of in-vehicle ITS technology at passive crossings would require either investments for trains or a centralised system to communicate with the vehicle, or the use of a mixed approach, combining dynamic information for already active crossings (through wireless communications) and static information at passive crossings. In-vehicle systems at active crossings would require the access (through wireless) to the information triggering the active controls. The crossing being active, this safety approach would complement already existing protections (active lights with or without boom gates). For both types of RLXs, this approach relies on market penetration (in terms of vehicles). The issues of likelihood of rapid market penetration and efficiency in terms of safety benefits remain. Such issues might be addressed by targeting vehicles at risk, such as trucks, and using already widely distributed devices such as in-vehicle GPS devices, PDAs and smartphones.

Various wireless protection systems with in-vehicle warning are currently developed, including EV-Alert (The Parliament of the Commonwealth of Australia, 2004), Pulsed LED RLX Signals (National Research Council, 2001) , Intelligent Crossing Controller (IXC) (Tardif, 2004), Railway Crossing Collision Avoidance System (Ogden, 2007, Welk, 1999), Emergalert system (Forester et al., 1994), and the use of Data Radio System (DRS) protocol and global positioning system (GPS) (Ogden, 2007). Such systems, the EV-alert for instance, can be installed for a cost of the order of $50,000 (Tey, 2009). On-road-based interventions can also be considered for active crossings. Active crossings, particularly those without boom gates, are of considerable concern in terms of safety. New approaches can complement current primary controls and should not be very expensive to implement (the expensive train detection system being already available at the crossing). An example of such approach is the trial of the valet system (on-road flashing markers) proposed by Queensland Rail.

# 4. HMI design of the ITS interventions

The technologies presented in the previous section have the potential to increase driver awareness at RLXs, using either in-vehicle or on-road warnings. Independently of the technology selected (through evaluation of reliability and cost), it is possible to provide new information to drivers that will increase their awareness at crossings through Human Machine Interface (HMI). With driver error being the main contributing factor to crashes at RLXs, it is important to assess whether driver behaviour will improve at RLXs with such HMI, whether new messages will have negative effects on their attention on the road and whether drivers would accept the new information provided to them. Requirements for the development of a HMI to increase driver awareness at RLXs is discussed in the following sections.

## 4.1. Human factors good practice at railway crossings

The Rail Safety and Standards Board's report (Rail Safety and Standards Board, 2011) highlighted the requirements for improving signals at railway crossings. Such requirements need to be used for any potential ITS device's HMI as well. Therefore:

- Using an ITS device and its HMI should not increase the cognitive load on the driver in a detrimental way, as the driver needs sufficient resources to collect and analyse information from the crossing and react appropriately if required. Therefore, any system which would increase driver cognitive load should be avoided.
- The salience of the crossing should be enhanced.
- Poor decision making from the driver should be reduced by preparing the road user for the need to attend to potential hazards.
- Sightlines should be improved in order to provide more time to the driver to make appropriate decisions at a crossing (a negative effect of this measure is the tendency of drivers to drive faster when approaching the crossing and this should be addressed). Using an ITS is a completely different approach but has the potential to provide the same benefits (and side effects) as the improvement of sightlines.

In relation to emerging technologies, Edquist, Stephan, & Wigglesworth (2009) suggest that human factors principles must be considered, so that warning systems reduce the cognitive and attentional load of the driver and safeguard against mental overload and distraction. Since vision and hearing are by far the senses of most relevance to driving, the choice of display modalities is generally limited to them (SELCAT, 2008). The choice of which of the two to use depends on a variety of factors. Visual form is preferred when the message is long and complex or deals with spatial references, no immediate action is needed, the message needs to be referred to later, or when hearing is difficult. Audible form is preferred when the message is short and simple, immediate action is needed, the message deals with events in time, or when vision is difficult (SELCAT, 2008).

## 4.2. Visual and audio HMI

Driving is primarily a visual task, and therefore safe driving largely relies on the human visual system. The human visual field is constrained by the direction in which one directs one's gaze. This restricts the awareness of hazards outside one's visual field. On the other hand, one is able to hear sounds regardless of the direction from which the sound is coming, but a noisy environment can reduce the effects of an audio warning. This makes sound a particularly useful medium for conveying safety critical messages (Sanders and McCormick, 1993). Visual and audio are therefore the HMIs most used in the driving context.

Visual HMIs are numerous in driving literature and are often robust. The characteristics of the successful visual HMIs in improving drivers' perception and decision making are:

symbolic representations rather than text, maximised contrast and position within an 10 degree area around the line of sight of the driver (Rail Safety and Standards Board, 2011). Also, visual HMI should be designed to ensure that the visual load is controlled. Otherwise, drivers tend to look less at the road centre area ahead, and instead look at the display area more often, for longer periods and for more varied durations (Engström et al., 2005).

Audio HMIs can be used in two different ways. Warning sounds can be used (abstract sounds such as 'beeps', auditory icons highly correlated to the event the warning is trying to highlight) or audio messages can be given to drivers. Speech-based warnings or auditory icons can improve comprehension. Although the evidence from the research is not consistent, there is some indication that meaningful sounds such as speech or auditory icons result in faster reaction times (Rail Safety and Standards Board, 2011). Effective audio signals are characterised by: a frequency and volume very different to ambient noise, a signal lasting more than 500ms, and a source of the sound in the same direction as the hazard (Ho and Spence, 2005). There is a maximum number of auditory signals which can be used (Weiss and Kershner, 1985). Twelve distinct warning sounds can be discriminated by trained operators on a relative basis, and only five if absolute identification is required. The advantage of using an audio warning is that drivers do not remove their eyes from the road as they process the information provided to them (Engström et al., 2005).

## 4.3. Vibro-tactile HMI

Another type of HMI can be used for ITS interventions, whether in-vehicle or on-road. Vibro-tactile cues (vibrations) can be given to the driver to attract their attention. For instance, it has been shown on a driving simulator that drivers can respond to a hazard on the road 25% faster with a vibro-tactile warning and manage to stop 34% further away from an object on the road (Ho et al., 2006). Nevertheless, such HMI faces two main issues. First, the warning has no iconic meaning and cannot be used to give precise information to the driver, which is an issue since ITS systems would provide a range of warning signals (not only for RLXs). Secondly, such methodology only has general spatial alerting abilities (Brown et al., 2005). Also, the research is scarce on the appropriate level of vibration to alert drivers with such HMI to cover the range of individual sensitivity to such vibrations (Rail Safety and Standards Board, 2011).

## 4.4. Combinations of HMIs

The previously described types of HMI can be combined to provide a range of cues to the driver about the same event. The most common combination is the use of both audio and visual signals. This generally improves the time required to respond to a stimulus as compared to a uni-modal warning (Ho et al., 2007). Such improvement is likely to be observed when both stimuli are presented from approximately the same spatial location at approximately the same time (Stein and Meredith, 1993, Stevenson et al., 2007). Such positive effects disappear when, for instance, an auditory cue positioned to the left or right is paired with a central tactile cue rather than with a tactile cue coming from the same direction as the auditory cue (Ho et al., 2009).

Unfortunately, in many situations the reaction time improvement resulting from multisensory warnings is likely to be small (Rail Safety and Standards Board, 2011), particularly in realistic environments, where warnings targeting multiples senses are likely to be given to drivers with some delay due to the need to combine multiple sensors (Brown et al., 2001). In the study by Lee, McGehee, Brown, & Marshall (2006), the warning signals were triggered by realistic algorithms and such experiments did not succeed in providing any advantage in terms of reaction times, although it was comparing the combination of visual, auditory, seat vibration, and brake pulse cues with uni-modal cues.

Therefore, uni-modal audio or visual warning should be preferred for providing information with new ITS technologies targeting RLXs.

# 5. Proposed methodology for evaluating effects of new ITS interventions at RLXs

Both potential positive and negative effects on safety of new ITS interventions for RLXs need to be assessed. A safe and controlled environment is required for conducting first trials of such new technologies with drivers. Using driving simulation provides safe conditions, a controlled environment, and repeatable and realistic driving conditions. Such equipment facilitates case control, before and after studies, and can be used to compare the effects of ITS interventions to current signals at RLXs. Finally, driving simulation allows quick and inexpensive ways to test many non-existent road safety interventions for railway crossings before trialling the most promising at a real RLX.

This project focuses on the HMI aspects of the technology and does not intend to build the hardware itself. It assumes that hardware conveys the required information reliably. It implements the interfaces with the highest potential to increase safety at RLXs. The HMI will only warn the driver that he has to stop at the crossing, either because a train is approaching or because the driver could not cross the railway safely. A mock-up of the most suitable technology will be simulated and tested in an advanced driving simulator.

Variables measured during the driving task can be measured with high reliability and high frequency, which enables measurement of driver behaviour in a very comprehensive way compared to on-road driving. The driving simulator provides all information about the car dynamics and environment, while appropriate sensors can provide information about driver behaviour and workload whilst performing the driving task. This provides a comprehensive picture of what is happening when the driver arrives at a RLX.

Different HMIs were considered to provide a warning to drivers, and the choice of which three HMIs to trial was formed by both literature review (see section 4) and consultation with focus groups of Queensland drivers. The effects on safety of these interventions will be compared to a baseline which presents only traditional warnings at crossings (no ITS intervention).

Another parameter of interest in this project is visibility when arriving at a crossing. A lack of visibility of the crossing can reduce the time the driver has to make a decision when arriving at the crossing. UK data, as reported by RSSB (2011), shows that the contributing factors to crashes at railway level crossings are often related to low visibility (for instance due to sunlight or turns in the road) or late braking decisions from the driver. While Ward and Wilde (1996) suggest that visibility would not significantly affect driver behaviour as drivers tend to maintain their safety margin regardless of improvement of visibility, it is of interest to evaluate whether ITS interventions improve behaviour at both active and passive crossings by providing information for safe decision making earlier. Indeed, ITS interventions enable drivers to be informed of the presence or absence of trains independently of the visibility of the crossing.

ITS also has the potential to improve driver awareness of the blocking back issue and increase the likelihood of a safe decision when arriving at the crossing, as was observed with vehicle activated signs on the side of the road in the UK study by McKenzie-Kerr, et al. (2011). Nevertheless, these positive effects were short-term and, when possible, the best solution is to remove or reduce the likelihood of a queue to form. ITS interventions trialled in our study enable drivers to be informed of the potential blocking back at the crossing, even though the signal is not activated for a train.

This proposed methodology for comprehensively assessing the effects of ITS interventions at RLXs will primarily assess the effects of such interventions on driver decisions and behaviour at railway crossings through the measurement of: compliance rates, driver awareness at the crossing (particularly eye tracking of the situation), driver perception of increased safety at the crossing with such systems, as well as driver acceptance of the system, speeding behaviour (particularly when the driver takes action to reduce speed when the situation 'train is approaching' is identified) and driver workload and distraction when processing the information at the crossing. Such measurements are presented in the following sections.

The research design is a 3 (ITS design: visual, audio HMIs and on-road intervention) x 2 (visibility: low and high) x 2 (traffic at crossing: low and blocking back) repeated measures experimental design. A control condition is implemented to record baseline driving performance with no ITS intervention. Participants are exposed to only one type of ITS intervention. For each ITS intervention, 30 participants will be invited to participate in order to detect differences of large sized effects due to the technology with a .9 power (at $\alpha$=.05). Repeated measures Analysis of Variance (ANOVA's) tests will be conducted for each measurements presented in the following section.

### 5.1. Drivers situational awareness

Driver's situational awareness can be accessed through both the driver's capacity to understand the situation and their performance and errors while driving (Durso and Sethumadhavan, 2008). As applied to railway crossings, performance and errors can be obtained by an analysis of the compliance rate and violation of the crossings (with train), an assessment of the safety of the speed when arriving at the crossing (with and without trains), and an assessment of reaction times when an active protection is activated or when a static sign is legible. The drivers' evaluation of the situation can be monitored through their eye gaze patterns as well as through questionnaires focused on driver's feedback about their situational awareness and their perception of safety at RLXs with and without assistance from ITS technology.

### 5.2. Distraction

The use of HMIs designed to assist in various driving situations is increasing (e.g., collision warning and avoidance, adaptive cruise control, lane departure, etc.). Although these systems are designed to benefit drivers, there are many instances where they can, and do, distract drivers from the primary task of driving. This is primarily due to the complexity involved, on the driver's behalf, in setting and monitoring the interface whilst driving. Therefore the effects of any new ITS interventions on driver distraction should be investigated. Such investigation will be done by analysing gaze patterns of the driver, which will provide information about their gaze fixations on signs at various crossings as well as of their gaze distraction from the road. The driver's control of the vehicle will also be monitored, through lane keeping for instance.

### 5.3. Mental workload

The effects of the technology on driver workload will be monitored with both physiological devices and subjective questionnaires. It has been shown that the physiological metric heart rate, if it changes at all, increases and the metric heart rate variability decreases during increased mental processing (Ahsberg et al., 2000, Oron-Gilad et al., 2008). The NASA-TLX will also be administered to participants in order to obtain their subjective assessment of the mental workload required for the drive (with or without the ITS).

### 5.4. Acceptance of the technology

After participants have used the ITS, their feedback about their acceptance of the technology will be collected via a questionnaire. This questionnaire is an adaptation of the Technology Acceptance Model (TAM) combined with the questionnaires used by the focus group and will assess the ease of use and perceived usefulness of the three ITS interventions.

## Conclusion

Research within the Australian context has indicated that interventions are required to reduce the number of crashes at both active and passive railway crossings. New ITS systems can help realising this aim by reducing driver errors at level crossings. The overall aim of this project is to evaluate the changes in driver behaviour at the approach of railway crossings when using new ITS technologies. This paper has highlighted the requirements for such technologies, from rail regulators, rail industry and drivers. There are a number of potential technologies which could be trialled and the best technologies in terms of safety potential, cost, and acceptance from drivers should be further investigated. Independently of the chosen technology, human factors issues need to be taken into account while providing new information to drivers. A methodology was proposed in this paper to comprehensively evaluate new ITS interventions in terms of compliance, control of the vehicle, mental workload and acceptance from the driver. ITS interventions are likely to improve drivers' awareness of the crossing status in low visibility conditions as well as in high traffic conditions with a risk of blocking back. This methodology will be implemented on an advanced driving simulator in order to evaluate the effects of ITS interventions on these issues at RLXs. The three most promising HMIs – audio, visual in-vehicle interventions and on-road flashing markers – have been selected based on a review of the literature, a cost/benefit analysis and a focus group of Queensland drivers, and will be investigated and compared during this experiment.

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