



Modelling driver behaviour towards innovative warning devices at railway level crossings

Li-Sian Tey^{a,d,*}, Guy Wallis^b, Steven Cloete^c, Luis Ferreira^a

^a Faculty of Engineering, Architecture and Information Technology, University of Queensland, QLD 4072, Australia

^b School of Human Movement Studies and Queensland Brain Institute, University of Queensland, QLD 4072, Australia

^c Minerals Industry Safety and Health Centre, University of Queensland, QLD 4072, Australia

^d Faculty of Civil Engineering, Universiti Teknologi MARA, 13500 Permatang Pauh, Penang, Malaysia

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ABSTRACT

Improving safety at railway level crossings is costly and as funds are often limited, it is important to search for cost-effective, evidence-based solutions. The effect that the many existing alternative systems have on driver behaviour is not always known. This paper compares driver behaviour towards two novel warning devices (rumble strips and in-vehicle audio warning) at railway level crossings with two conventional warning devices (flashing light and stop sign). Regression models were developed to reflect driver's responses towards the four different types of devices based on data collected from a driving simulation experiment. The regression models include a binary choice model for predicting the probability of a driver stopping or driving through a railway crossing, as well as mixed regression models for predicting the moment at which a driver will produce specific behavioural responses before stopping at a crossing (e.g. initiation of accelerator release and application of foot-pedal brake). Violation results indicated the active systems produced much higher levels of driver compliance than passive devices. Contributing factors, such as age, gender, speed and types of warning devices were found significant at different approach stages to the level crossings. With the application of such behavioural models and traffic conflict techniques in microscopic simulation tools, traffic safety indicators, such as collision likelihood and time-to-collision can be estimated. From these, relative safety comparisons for the different traffic devices are derived.

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1. Introduction

1.1. Background

Safety at railway level crossings is a world-wide issue, which increasingly attracts the attention of transport authorities, the rail industry and the public. The financial cost of a level crossing collision of a train with a road vehicle is often quite high. Governments, the rail industry and others have been applying a variety of countermeasures for many years to improve railway level crossing safety. These actions are substantial and have resulted in a continuing decrease in the number of level crossing crashes and their severity. In Australia, records show improvements in safety with the use of active crossing systems (Wigglesworth and Uber, 1991; Ford and Matthews, 2002). However, the cost to eliminate

or upgrade passive crossings is very high. Estimates for installing flashing lights or boom barriers (active protection) at all passive crossings in Australia, is not cost-effective for the number of fatalities per year. Estimates to install active protection (approximately \$600,000 per crossing) at all public passive crossings in Australia (approximately 6000) are approximately \$3.6 billion (Wallace et al., 2010). On-going maintenance costs would likely be considerable in view of the remote location of many passive crossings. Furthermore, vehicle collisions at crossings are frequently – if improperly – attributed to driver behaviour (i.e., non-compliance) in response to the warning device (Australian Transport Council, 2003). In view of that, researching cost-effective alternative systems, from a human-centred perspective which avoids simplistic notions of 'blaming the driver', is a worthwhile undertaking.

In the present study, rumble strips (a potential passive crossing installation) and an in-vehicle audio warning (a potential active in-vehicle device) were investigated. A driving simulator was used to collect behavioural data. These data were then fed into a driver behavioural model suitable for inclusion in microscopic simulation tools, which are used to estimate a variety of safety outcomes, such as collision likelihood and time-to-collision. Driver behaviour

* Corresponding author at: Faculty of Engineering, Architecture and Information Technology, University of Queensland, Brisbane St. Lucia, QLD 4072, Australia. Tel.: +61 733653619; fax: +61 733654599.

E-mail addresses: teylisian@uq.edu.au, teylisian@yahoo.com (L.-S. Tey).

towards the two alternative warning devices at crossings (rumble strips and in-vehicle audio warning) was compared with current conventional devices (stop sign and flashing lights). Factors which are known to influence responses of drivers to traffic devices were included as predicting variables, including age (Caird et al., 2002; El-Shawarby et al., 2007; Yeh and Multer, 2007; Bao and Boyle, 2008), gender (Caird et al., 2002; El-Shawarby et al., 2007; Bao and Boyle, 2008; Tey et al., 2011) and speed (Moon and Coleman, 1999; Caird et al., 2002; Park and Saccomanno, 2005).

1.2. Previous research

Warning devices at level crossings have been the subject of much empirical research, and although debate is not settled as to which devices offer the greatest promise for inclusion in road/rail networks, findings tend to indicate greater effectiveness for warnings with active content (Caird et al., 2002; Tey et al., 2011). Nevertheless, in one study by Pickett and Grayson (1996), results from the interviews of drivers who had been seen to cross level crossings when the red stop lights were flashing, suggested that the majority of respondents showed an understanding of the operation of the crossings, suggesting a wilful neglect of traffic signals. On the other hand, Jeng's (2005) findings from a study in New Jersey suggested that some traffic control devices used in the vicinity of level crossings, such as stop signs and traffic signal lights, confused drivers, leading to failed understanding rather than wilful neglect, suggesting there is a need to improve the understanding and compliance of drivers.

Rumble strips are transverse strips in the pavement, either raised above the pavement or grooves formed in the pavement, which give an audible and tactile sensation to the driver of a vehicle passing over them (Transport and Main Roads, 2010). The premise behind their operation is that the increased noise, vibration and occupant discomfort associated with travelling over them at high speed will encourage drivers to slow down. They may relatively reduce the possibility of 'wilful neglect' by drivers. Several studies have revealed that installation of rumble strips results in speed reduction (Gorrill, 2007; Gates et al., 2008; Hore-Lacy, 2008), which may lead to positive safety outcomes. In-vehicle technologies, such as in-vehicle warnings, constitute an alternative system which could form part of a broader intelligent transportation system countermeasure. The device warns drivers of the presence of a train via a visual and/or audio warning in their vehicles. Audio warning sounded 'train approaching, crossing, departed' may possibly reduce issue of 'failed understanding of the traffic control devices' by drivers. Two recent simulator studies (Kramer et al., 2007; Porter et al., 2008) reported benefits of in-vehicle auditory warning devices, with the latter study demonstrating particular reductions in brake response times for senior drivers.

Since these two devices are not yet common or in use in the traffic network, it is difficult to test driver behaviour and other direct safety measures, such as collisions, using field studies. There are significant barriers to field research using prototype warning devices, including low road and rail traffic volumes (which have implications for observation times), concerns related to safety and potential disruption of the road/rail network, and ethical considerations associated with observing and measuring drivers' behaviour without their consent. Investigating the efficacy of traffic control devices in driving simulators has numerous advantages over on-road studies, including higher degrees of safety and experimental control, and smaller investments of time and expense. In the current study, measurements of vehicle control in the presence of level crossings, including pedal release and activation, as well as the more concrete safety-related measure of warning violation, have been obtained from a sample of drivers in a fixed-base driving simulator. These measures have then been used as criterion variables

in two regression models. With the application of such behavioural models and traffic conflict techniques in microscopic simulation tools, traffic safety indicators such as collision likelihood and time-to-collision between a vehicle and a train can be estimated.

The current paper develops regression models to predict drivers' responses towards the four different types of warning devices. Two aspects of driver behaviour were investigated. A binary choice regression model was developed for predicting the probability of stopping at a railway crossing. In addition to driver compliance at a crossing, mixed regression models for predicting drivers' reaction positions (accelerator release, initial brake and final brake) before stopping at the crossing were also implemented; with categorical predictor variables for the different types of warning devices, vehicle approach speed, and drivers' gender and age. This paper is structured as follows: Section 2 briefly describes the data collection; Section 3 presents the model development and discusses the results; and finally, Section 4 concludes the main findings and discusses future investigations.

2. Methods

2.1. Participants

Twenty-four volunteer drivers aged 17–66 years (4 males and 4 females aged 17–30 years, 4 males and 4 females aged 31–50 years, 4 males and 4 females aged over 50 years) were recruited from the local community and university population to participate in a driving experiment.

2.2. Apparatus and stimuli

The experiment was conducted in a fixed-base driving simulator, comprising a Silicon Graphics Onyx 3200 graphics engine, custom OpenGL software and BARCO 808 CRT overhead projector. Images were rendered at 1280 × 1024 resolution with 32-bit colour depth at a rate of 36 Hz, and projected onto a 3.2 m × 2.7 m flat white screen situated 2 m from the driving seat. The horizontal subtense of the simulator images was approximately 106 degrees of visual angle. Eye height was set at 1.1 m. A Logitech MOMO force feedback steering wheel was used to steer through a virtual environment, which included level crossings with the four different warning devices was developed. The virtual environment consisted of a gently curving, two-lane rural roadway.

For trials in which a train was approaching, the train only became audible, and ultimately visible, once the participant came to a complete stop. As soon as the driver pulled up to the stop line, a distant rumble became audible to the driver's left. The train then took 20 s to reach the level crossing and cross in front of the vehicle. During its approach the sound of the train steadily increased and then subsequently diminished as it continued on its way off to the driver's right. Passage over rumble strip was simulated using the force-feedback steering-wheel for both vibratory sound and steering-wheel movement. Parameters for this vibration were chosen by trial-and-error until a firm oscillation was produced that had the same subjective impact on the experimenters as driving over real rumble strips at the simulated speeds used in the experiments. This vibration was then triggered by drivers moving over the rumble strips.

2.3. Experimental design and analysis

A mixed factorial design was employed. Participants were categorised by age and gender as described above, with four participants in each level combination of these between-subjects factors. Each participant completed a series of experimental trials conforming to a 4 × 2 × 2 × 3 within-subjects design, with warning

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