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Microsimulation modelling of driver behaviour towards alternative warning devices at railway level crossings

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ABSTRACT

Level crossings are amongst the most complex of road safety issues, due to the addition of rail infrastructure, trains and train operations. The differences in the operational characteristics of different warning devices together with varying crossing, traffic or/and train characteristics, cause different driver behaviour at crossings. This paper compares driver behaviour towards two novel warning devices (rumble strips and in-vehicle audio warning) with two conventional warning devices (flashing light and stop sign) at railway level crossings using microsimulation modelling. Two safety performance indicators directly related to collision risks, violation and time-to-collision, were adopted. Results indicated the active systems were more effective at reducing likely collisions compared to passive devices. With the combined application of driving simulation and traffic microsimulation modelling, traffic safety performance indicators for a level crossing can be estimated. From these, relative safety comparisons for the different traffic devices are derived, or even for absolute safety evaluation with proper calibration from field investigations.

1. Introduction

Level crossings are amongst the most complex of road safety issues, due to the addition of rail infrastructure, trains and train operation. Generally, there are several contributory factors to level crossing collisions and these can be difficult to determine. Nevertheless, in Australia, collisions at crossing are reported to be mainly attributed to drivers' responses to the warning devices (Australian Transport Council, 2003; Wallace et al., 2008; Chartier, 2000, etc.). The differences in the operational characteristics of different warning devices together with varying crossing, traffic and/or train characteristics, cause different driver behaviour at crossings. Several different types of warning devices are used at crossings, which recent research has shown have significantly different effects on driver behaviour (Yeh and Multer, 2007; Caird et al., 2002; Tey et al., 2011). In view of that, considerable research and innovation has occurred in some countries on the development of low-cost warning systems for level crossings. In the present study, rumble strips (a potential passive device) and in-vehicle audio warnings (a potential active in-vehicle device) were investigated.

Human factors (driver behaviour) identified were generally driver characteristics, unintended human errors, intentional actions and risk seeking behaviour. Among driver characteristics, age-related (Schoppert and Hoyt, 1968; Yeh and Multer, 2007; Caird et al., 2002) and gender-related factors (Caird et al., 2002; Abraham et al., 1998; Tey et al., 2011) were acknowledged to be risk factors at level crossings. Compensatory and protective factors employed by older drivers were believed to reduce or control their risk. Younger drivers demonstrated a low perceived risk of consequences in relation to level crossing behaviour and subsequently reported the highest levels of risk taking of all the sub groups. A study of driver behaviour at 37 rail-highway crossings in Michigan, US, revealed that the drivers aged between 25 and 40 years was observed to commit more violations than any other age group. Of these, male drivers committed more violations than female drivers (Abraham et al., 1998). However, a previous study (Tey et al., 2011) conducted in Queensland, Australia, observed that more female drivers (24%) than male drivers (14%) drove through a passive crossing without stopping or slowing down. The relationship of drivers' stopping compliance behaviour (violation) and braking responses at level crossings in particular to influences of speed, age and gender

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has been studied and driver behavioural models developed (Tey et al., 2013a). These models were adopted in this paper for the microsimulation and are detailed in Section 2.

Traffic micro-simulation models have a number of restrictions for traffic safety analyses. This limitation is mainly attributed to the high degree of variance in driver perception, reaction and driving behaviour and errors. Nevertheless, recent years have witnessed the appearance of several approaches to traffic safety issues in traffic micro-simulation. For instance, Cunto and Saccomanno (2008) used VISSIM 4.3 to estimate the safety performance for individual vehicles, which is expressed in terms of a crash potential index at the intersection, Piao and Mcdonald (2008) used AIMSUN to assess safety impacts of Variable Speed Limits (VSL) while Ozbay et al. (2008) suggested modified-TTC (MTTC) and a new crash index (CI) in conjunction with use of Paramics. In this paper, two safety performance indicators directly related to collision risks were adopted; namely, violation and 'time-to-collision' (TTC). 'Violation' refers to non-adherence of the traffic rules or traffic control devices (i.e., running red light, not stopping at a stop sign, etc.). Abraham et al. (1998), in their studies to test the relationships between driver violations and railway level crossing collisions, revealed promising use of violation data in determining the relative hazardousness of level crossings in combination with crash histories. Violation data were related to driver characteristics such as age, gender and to the types of warning devices (Tey et al., 2013a). Violation data may also be used to develop countermeasures that would help alleviate violations and eventually traffic collision problems at railway level crossings. The concept of TTC was defined by the US researcher Hayward (1972) as the time at which two vehicles would possibly collide if they keep their current speed and steering (Hayward, 1972; Hyden, 1996; Lundgren and Tapani, 2006). The TTC value decreases with time to 'zero' as the vehicles approach their conflict point and collide. The value of TTC in various situations in which traffic conflicts frequently happen has been studied by many researchers (Van Der Horst, 1991; Hirst and Graham, 1997; Hogema et al., 1996; Van Der Horst, 1990). The minimum and critical TTC values identified for approaches at intersections are 1.1 and 1.6 s (Van Der Horst and Brown, 1989) and 1 and 1.5 s (Van Der Horst, 1991), respectively, while the critical TTC for unintentionally dangerous situations is 4 s (Hirst and Graham, 1997).

This paper incorporates and presents an application of the driver behavioural models (Tey et al., 2013a) into a microscopic traffic simulation using MATLAB in order to model driver behaviour for safety performance evaluation in terms of the likely number of collisions and TTC. It shows the potential of combined application of driving simulation and traffic microsimulation modelling for evaluating safety performance of the railway level crossing warning systems. The paper is structured as follows: Section 2 provides background information of data collection and driver behavioural models developed; Section 3 discusses the contributing variables under consideration; Section 4 provides a brief description of model development and the results of the simulation; and Section 5 concludes the main findings.

2. Background of data collection and the driver behavioural models

The data used for the driver behavioural models adopted in this paper were collected from a driving simulator experiment (Tey et al., 2013a). Twenty four volunteers ranging in age from 17 to 66 years were recruited from the local community and The University of Queensland for a driving simulation experiment conducted in a fixed-base driving simulator located in 10 m × 5 m laboratory. The simulator comprised an overhead projector, a force-feedback steering wheel, and an accelerator and brake pedals. Three-dimensional images were projected onto a 3.2 m × 2.7 m flat, white projection screen at a distance of 2 m from the 'driving seat'. A controlling computer recorded foot pedal and steering-wheel data of each frame. A virtual environment was developed, which consisted of a simulated two-lane two-way road with a level crossing. Four different types of warning devices appeared randomly at the crossing. Two of the conventional warning devices (stop sign and flashing red-lights with bell) were included as 'baseline' comparisons with two innovative warning devices (rumble strip with stop sign and in-vehicle audio warning). The stop sign and rumble strip (with stop sign) are passive devices while flashing red-lights and in-vehicle audio warnings are activated by train presence at a single track crossing. Rumble strips alert drivers of a crossing ahead through vibration and sound. In the simulation this was imitated by vibrating the force-feedback steering wheel. The in-vehicle audio warning triggered verbal cautions: 'Warning! Train approaching!', 'Train crossing! Stop at the stop line!' and 'Train departed. Please proceed'. The participant drivers were advised to maintain the fixed maximum speed assigned until they encountered a stimulus or traffic hazard where they were expected to react as they would in the real world.

For each test trial, data on vehicle trajectories, including brake and accelerator activation, were recorded. From the vehicle trajectories, the following data were retrieved:

(i) Driver stopping compliance at crossings (whether subject stopped or crossed at crossings);
(ii) Position at which driver released the accelerator;
(iii) Position at which initial brake was applied; and
(iv) Position at which final brake (final maximum slope change of time-space curve) was applied before stopping.

After data analysis, regression models were developed to reflect driver's responses towards the four different devices. The contributing variables tested were gender, age, speed and warning devices. Different variables were found significant for different approach stages to the level crossings at different levels of confidence statistically. Driver behavioural models were developed. The regression models included 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 produced specific behavioural responses before stopping at the crossing (e.g., initiation of accelerator release and application of the brake foot–pedal); namely, initiation of accelerator release (AccR), initial (IniBr) and final (FinalBr) applications of brake foot–pedal, measured in distance from the stop line (m), in the form of Eqs. (1)–(4).

$$P_i(\text{cross}) = \frac{1}{1+e^{-z_i}}$$
$$z_i = -1.26 - 0.96X_{\text{gender}} + 1.72X_{m.\text{age}} - 3.12X_{\text{FL}} - 2.39X_{\text{IV}} \quad (1)$$
$$P_i(\text{stop}) = 1 - P(\text{cross})$$

$$\text{AccR}_{ij} = 182.36 - 11.12X_{\text{FL}} - 7.82X_{\text{speed}} \quad (2)$$

$$\text{IniBr}_{ij} = 104.97 - 17.36X_{\text{FL}} - 13.84X_{\text{IV}} - 13.92X_{\text{speed}} \quad (3)$$

$$\text{FinalBr}_{ij} = 20.73 - 4.96X_{\text{gender}} + 5.46X_{y.\text{age}} + 16.3X_{\text{FL}} + 18.38X_{\text{IV}} \quad (4)$$

where P_i (cross = 1): the probability of the ith vehicle crossing (violating warning device); P_i (stop = 0): the probability of the ith vehicle stopping (complying to warning device); X_{speed}: speed, comparing 80 km/h (1) to 60 km/h (0); X_{gender}: gender, comparing female (1) to male (0); $X_{m.\text{age}}$: age, comparing the age group of 31–50 years (1) to the age group of >50 years (0); $X_{y.\text{age}}$: age, comparing the age group of 17–30 years (1) to the age group of >50