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Using a driving simulator to assess driver compliance at railway level crossings

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Abstract

Railway level crossings have the potential to bring motor vehicles and trains into fatal contact. In Australia there are approximately 9,400 public railway level crossings across the country, protected either passively (64%) or by active/automated systems (28%). Passive crossings provide only a stationary sign warning of the possibility of trains crossing. Their message remains constant over time. Active systems, by contrast, activate automatic warning devices (i.e., flashing lights, bells, barrier, etc.) as a train approaches. Using a driving simulator, this paper compares driver compliance at railway level crossings equipped with either active or passive warning devices including a stop sign, rumble strips, flashing lights/bell and in-vehicle auditory warning. This paper describes the driving simulator data collection and findings and subsequently draws conclusions on driver compliance with respect to different types of warning devices. The results indicate that drivers behave differently and are more compliant at active crossings than at passive crossings.

Keywords:

Railway level crossing, alternative warning devices, driver compliance, driving simulator.

1. Introduction

Railway level crossings (RLX) create serious potential conflict points for collision between road vehicles and a train or trains, producing one of the most severe in all traffic crash types. Accidents at level crossings continue to be the largest single cause of fatalities from rail activity in Australia (Bureau of Transport and Regional Economics, 2002). There are approximately 100 incidents at Australian crossings every year and these incidents result in the death of an average of 37 people (Australian Transport Council, 2010). During the years 2007 to 2009, there was an average of 55 collisions at crossings involving road vehicles per year (Australia Transport Safety Bureau, 2010). The annual cost of RLX collisions has been estimated at AUD$32M,excluding rail operator and infrastructure losses (Bureau of Transport and Regional Economics, 2002). There are approximately 9,400 public crossings in Australia. They are protected either passively (64%) or actively by automated systems/devices (28%) (Ford and Matthews, 2002). Passive crossings provide only stationary signs without train information. Drivers have to look for the presence of a train before clearing the crossing. An active warning system, by contrast, activates automatic warning devices (i.e., flashing lights, continuous bell, etc.) as a train approaches. In Australia, records show a reduction in accidents following the installation of active warning systems (Wigglesworth and Uber, 1991; Ford and Matthews, 2002). However, improving safety at RLX is costly. The cost of an active level crossing protection system is generally accepted at approximately AUD$500,000 per crossing (Graham and Hogan, 2008). The cost of installing conventional active systems at all passive crossings in Australia would therefore be as high as AUD$3 billion. In addition, on-going maintenance costs would be considerable in view of the remote location of many current passive crossings. The search is therefore on, to find new, cost-effective technologies. This search has been identified in the National Railway Level Crossing Safety Strategy 2010-2020 as one of the key actions to be addressed (Australian Transport Council, 2010).

Considerable research and innovation has occurred in some countries on the development of low cost RLX warning systems at the crossing, on trains, or in vehicles. A recent comprehensive literature review identified approximately 50 different systems (Tey, 2009). Although many of these systems have been invented, their effect on safety and driver acceptance is unknown. There are opportunities for immediate application of some low-cost innovative systems for RLX available worldwide, subject to their effectiveness and adaptation to Australian conditions. The effectiveness of these alternative systems needs to be assessed to reflect safety improvements at crossings. However, to date, there has been no systematic approach available to evaluate these systems for implementation in Australian conditions other than before-and-after implementation studies.

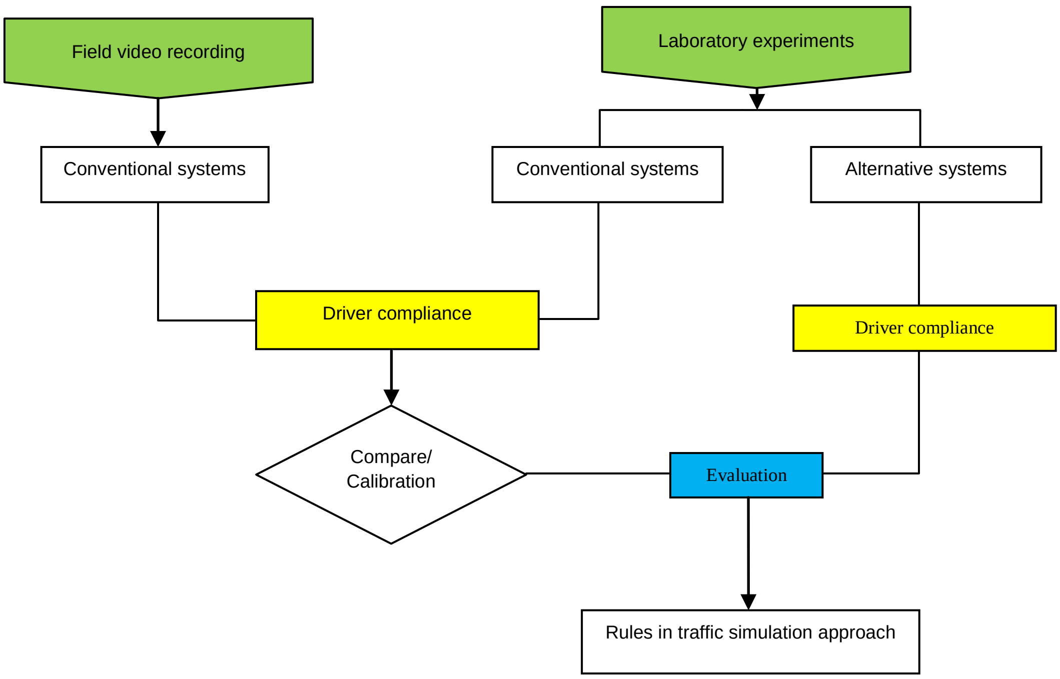
To compare the effectiveness of these innovative systems with currently used systems, it is necessary to assess their impact on driver behaviour. ‘Driver compliance’ is one of the parameters commonly used to test driver behaviour at crossings. This parameter was adopted in some studies of both existing systems and newly invented systems (Shinar and Raz, 1982; Meeker et al., 1997; Carlson and Fitzpatrick, 1999; Hirou, 1999; English and Murdock, 2005). Abraham et al. (1998) presented a possible association between violations of road rules and past crash histories at crossings. The current paper compares driver compliance of two alternative warning systems (rumble strips and in-vehicle auditory warning) with two conventional warning devices (stop sign and flashing light) using a driving simulator. This paper is structured as follows: Section 2 provides a description of the study’s background and methodology of data collection; Section 3 presents and compares the results from the driving simulator experiment, and Section 4 draws conclusions from the main findings.

2. Methodology

2.1 Background

The driving simulator results reported in this paper are part of a study aimed at developing a methodology to evaluate alternative warning systems for level crossings from the aspects of engineering considerations and human factors. For engineering evaluations, a few potential systems which would suit the objective of the research were selected as examples using a multi-criteria analysis technique (Tey et al., 2009). For the human factor aspect, driver responses towards the warning systems were measured both in the field as well as in the laboratory using a driving simulator. One of the important driver responses considered is driver compliance, since higher records of violations may indicate a higher possibility of collisions with trains. Figure 1 briefly outlines the interface between the two approaches. The driver compliance rates measured from different types of conventional warning systems in the field (Tey and Ferreira, 2010) were compared to the results of driver compliance from driving simulator experiments in the next stage of the study. Subsequently, driver compliance to alternative systems in driving simulator was assessed. Driving simulator experiments were designed to involve human factors (i.e., age and gender) in determining contributing variables of driver behaviour to different types of warning systems. The results will be incorporated into a microscopic traffic simulation approach in the next stage of the study. The interface of driver behaviour results from the driving simulator into a traffic simulation approach will enable innovative RLX warning systems to be evaluated in laboratory controlled conditions. The output of this study will contribute to the evaluation process of innovative RLX warning systems taking into consideration both engineering and driver behaviour factors.

Figure 1: Driver compliance evaluation with field survey and driving simulator experiments



2.2 Driving simulator setup

Participants

Twenty four volunteers ranging in age from 17 to 66 years (4 male and 4 female from below 30 years, 4 male and 4 female from 31 to 50 years, 4 male and 4 female from above 50 years) were recruited. The drivers were asked to drive normally, as they would in a real car. The exact nature of the study was withheld until after completion of the experiment, so as to avoid eliciting artificially high levels of vigilance or compliance.

Development of Simulated Driving Task Environment

The experiment was conducted in a fixed-base driving simulator in the Perception and Motor Systems Laboratory at The University of Queensland. 3D images were projected onto a 3.2 m x 2.7 m white flat projection screen at a distance of 2 m from the ‘driving seat’. A controlling computer acquired foot pedal and steering-wheel data at each frame (time step).

A virtual environment simulation was developed. Once a start button was pressed and the accelerator pedal activated in each trial of a session, the participant was required to ‘drive’ in the left-hand lane of a simulated two-lane two-way road at a designed constant speed by manipulating the steering wheel. Participants had the visual impression of driving along a curved road. A digital speedometer at the central bottom of the display screen showed the vehicle’s headlong speed. Figure 2 provides a schematic illustration of the simulated crossings. The distances specified in Figure 1, pertaining to the RLX layout and warning sign placement, are based on RLX design specifications contained in the MUTCD Part 7. According to MUTCD Part 7 (Standards Australia, 2009), on uncurbed roads in rural areas, signs shall be at least 600 mm clear of the outer edge of road shoulder. Clearance should be not less than 2 m or more than 5 m from the edge of the travelled way. The height of the sign should normally be not less than 1.5 m above the nearest edge of travelled way. After approximate 1.0 km of driving, driver approached a level crossing. All level crossings that drivers encounter during the scenarios have same road characteristics as listed in Table 1, with four different types of warning devices appeared randomly at the crossing. Two of the conventional warning devices (stop sign and flashing red-lights) were included as controlling samples for another two alternative warning devices (rumble strips and in-vehicle audio warning). Stop sign and rumble strips are passive devices while flashing red-lights and in-vehicle audio warnings were activated by train present at a minimum of 20 sec prior to the arrival of a train at a single track crossing (based on (Standards Australia, 2009)). Passive crossing with stop sign provides only stationary signs without train information. Drivers have to stop to search for the presence of a train before clearing the crossing. Rumble strips are transverse strips raised above the pavement that give an audible and tactile sensation to the motorists passing over them. Other than the stationary signage identical to stop sign, rumble strips alert driver of crossing ahead by wobbling/tactile sensation from the steering, while travelling through the transverse strips. It is designed according to Transport and Main Roads (2010) as shown in Figure 3. Flashing-red-light signal consists of twin red round lights arranged horizontally and equipped to flash alternately. In-vehicle-audio-warning plays a set of verbal warning when activated by a approaching train: ‘Warning! Train approaching!’, ‘Train crossing! Stop at the stop line!’ and ‘Train departed. Please proceed.’ (the initial warning was played 21secs prior to the train arriving at the crossing, the second was played as the train passed and the third was played after the train had departed). Figure 4 shows a snap shot from the simulation and the four different types of warning devices included.

Figure 2: Typical schematic illustration of the simulated roadway

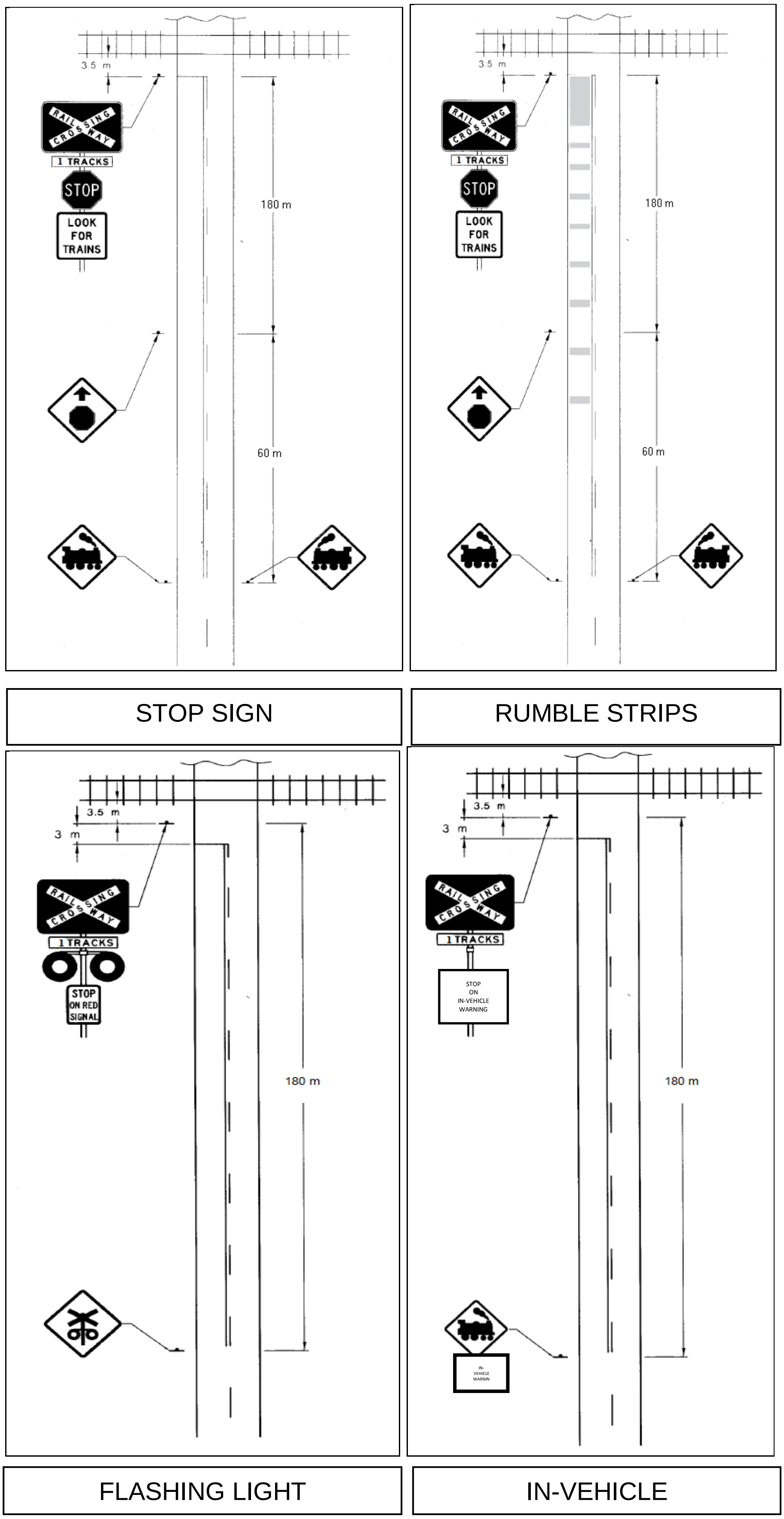


Table 1: Road and crossing characteristics

Characteristic	Simulated Environment
Road type	Two-lane two-way sealed pavement road in a rural setting
Number of train tracks	One
Horizontal alignment of road	Straight road approaching level crossing
Vertical alignment of road	Level
Road length	1.0 km
Lane width	3.5 m
Vehicle	No other vehicle on the road
Road speed limits	Constant at either 60km/h or 80km/h
Train speed	50km/h
Train length	3 cars x 69.5 m/car
Rail-road angle to road	90°

Figure 3: Layout of rumble strips design

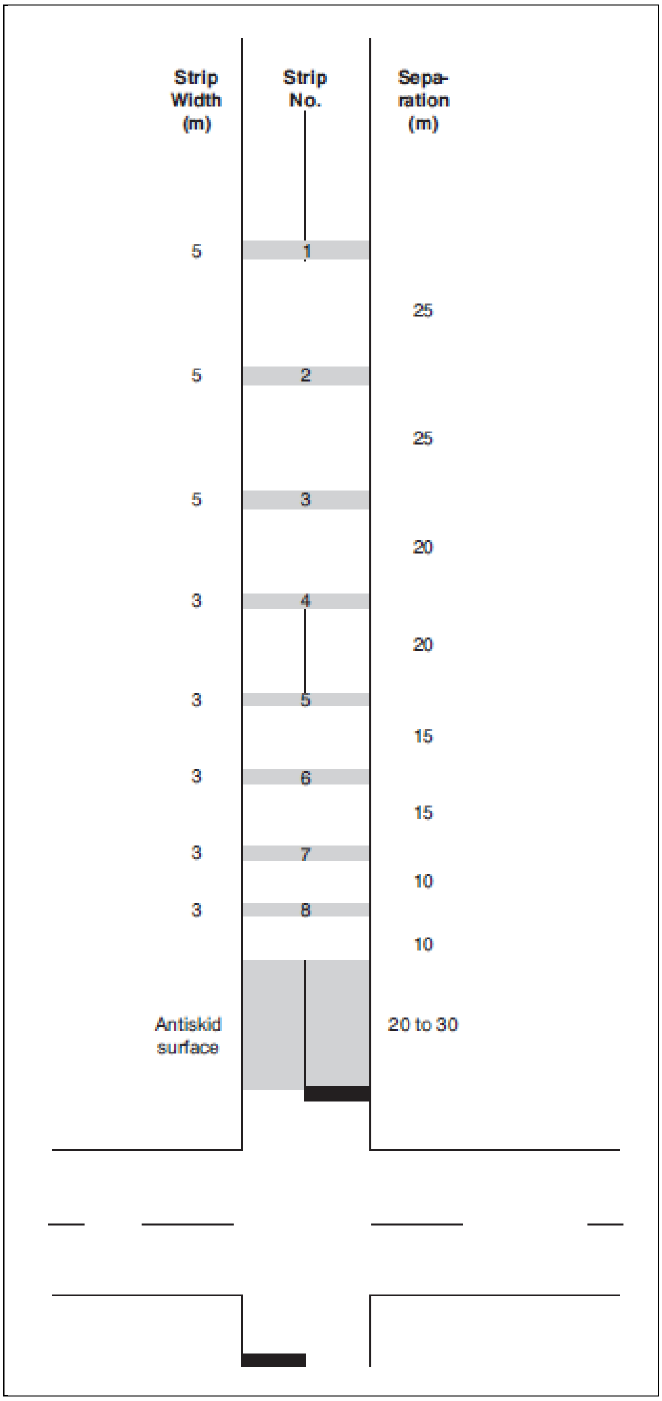
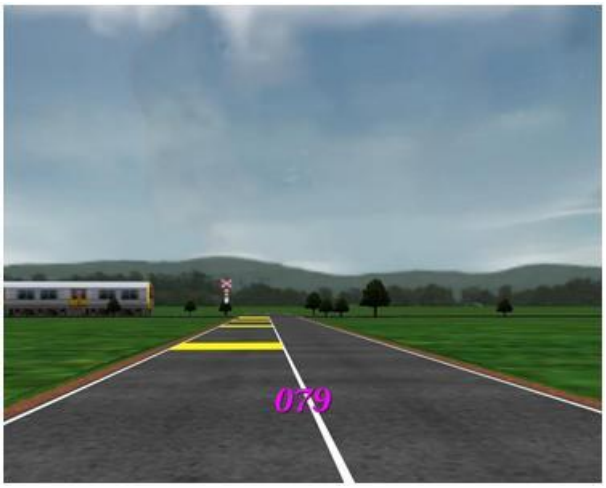
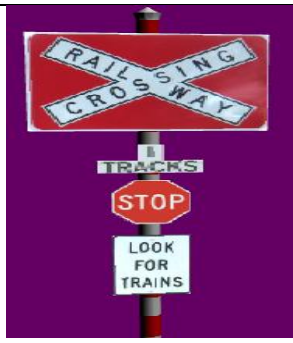


Figure 4: A snap shoot of photo from the simulation and the four different types of warning devices included in the simulation



			
Flashing Light	In-vehicle Audio	Rumble Strips	Stop Sign

The four warning devices and the associated advance warning signs were included on the left shoulder of the roadway, as shown in the schematic layout in Figure 2. Sufficient times were allocated for driver's responses when approaching the crossing before train present. This timing provides an opportunity for the driver to react particularly to the warning devices but not due to the train present. The initial speed was chosen in pseudorandom order to be either 60 or 80 km/hr. The participants were advised to maintain the constant speed until they encountered a stimulus or traffic hazard which they should react to as they would if driving in the real world. Potential reactions included releasing the accelerator to slow down gradually; releasing the accelerator and pressing the brake to slow down further or more abruptly; stop completely; slow down then accelerate to proceed; and proceed without slowing down.

Pilot Testing of Scenarios

A pilot test was conducted for preliminary observations and so as to acquire the following information:

- i) Total duration to traverse the simulated driving task and total duration to complete the entire experiment;
- ii) Any feature or technical issue of the simulated environment simulation needing modification or adjustment;
- iii) Subjects' opinions about how real the environment felt (specifically issues for improvement);
- iv) Testing for the possible onset of motion sickness during the drive.

Four subjects took part in the pilot test. Minor adjustment to the virtual simulated environment and the experiment design were made as a result.

Procedure of Main Experiment

The duration of the entire experiment was approximately 1 hour, consisting of briefing, training, testing and post-testing questionnaire sessions. During an initial familiarisation phase, subjects were asked to perform a series of manoeuvres, such as accelerating to a desired speed limit, slowing down and stopping immediately.

In each trial of the actual test, a subject encountered 4 level crossings with different warning devices: stop sign, rumble strips, flashing red-lights and in-vehicle warnings. The sequences of the types of warning devices were pseudorandom. Hence the subject could not foresee the warning type in the subsequent crossing. The vehicle maximum speed was randomly fixed to either 60 or 80 km/hr in each stretch of roadway approaching the crossing. This setup allowed the subject to break in between trials whenever they felt necessary. An entire testing session consisted of 12 test trials. These 12 trials involved 3 repetitions of the combination of varying scenarios: 60 or 80km/hr (2 conditions) and with or without train (2 conditions) and 4 types of warning devices (4 conditions). Thus, each successive subject produced 48 (3 x 2 x 2 x 4) sets of experimental data. The screen came to completely black which indicating the experiment had been completed. The process of the entire test could be monitored through another computer linked outside of the laboratory.

For each test trial, data on vehicle trajectories were recorded. These data were generated from 'accelerator and brake pedal' resulting from the driver's responses to the stimulus encountered in the virtual environment. From the vehicle trajectories together with monitoring through the computer linked outside the laboratory during the tests, driver compliance could be assessed at each crossing.

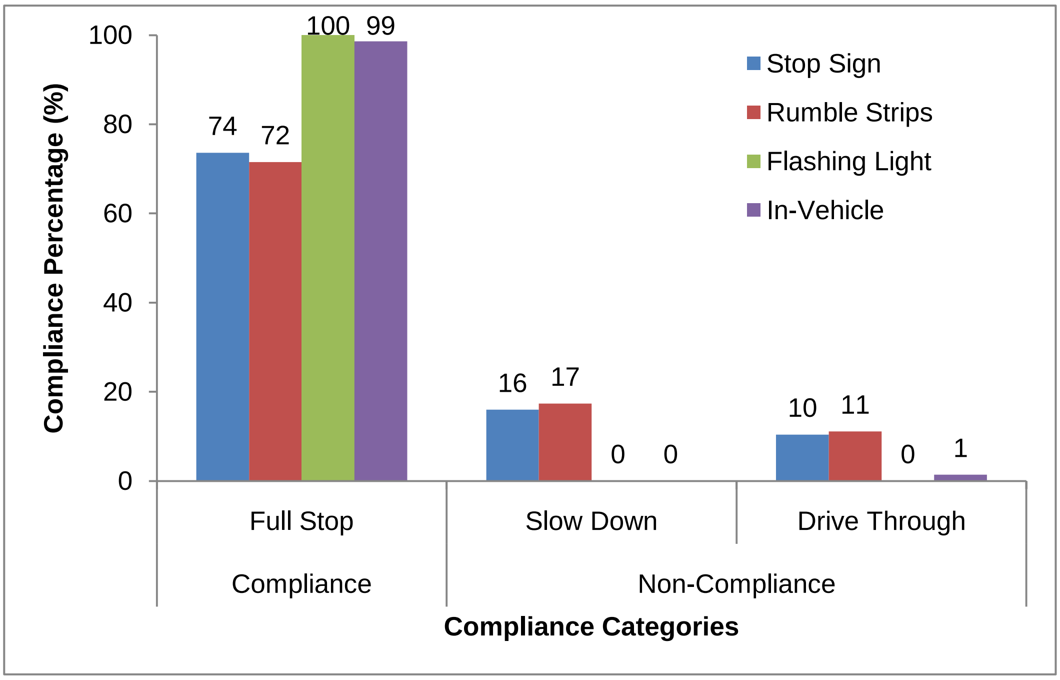
After completing the testing session, subjects were asked to answer a post-experimental questionnaire, focusing on effectiveness of the warning devices. A short interview was also conducted to discuss the subject's responses in the experiment.

3. Data analysis and findings

Drivers approaching a crossing with a 'stop sign' are expected to obey the regulatory sign to *stop* the vehicle before the stop line regardless of the presence of a train. For active systems, either the 'flashing-red-light' or 'in-vehicle-audio-warning', drivers are required by the road rules to stop when the red-light or audio-warning were activated by an approaching train. Thus, in the driving simulation experiment, driver stopping compliance for passive devices (stop sign (SS) and rumble strips (RS)) were investigated for both scenarios of with and without train, while only the scenario with train for active devices (flashing-red-light (FL) and in-vehicle-audio-warning (IV)) were considered.

Drivers' stopping compliance at crossings with different warning devices was recorded. Two conventional warning devices, flashing-red-light (active) and stop sign (passive), were designed as controlling samples for comparison with two innovative warning devices, in-vehicle-audio-warning (active) and rumble strips (passive). Non-compliance behaviours at all crossings in the simulated drives were observed and sub-categorised to 'Slow Down' (reduced speed then continued to cross) or 'Drive Through' (neither fully stopping nor reducing speed). These sub-categories indicated drivers' compliance behaviour at the four types of warning devices. Figure 5 shows compliance percentage of the drivers towards the four different types of warning devices in the simulated drive. Only stopping compliance results for approaching speed of 60km/hr are reported in this paper. Almost all drivers came to a complete stop at both the active systems, flashing-red-light and in-vehicle-audio-warning (100% and 99% respectively). The 1% of 'Drive Trough' for in-vehicle-warning was contributed by one subject in the final trial. The subject explained that it is learned from the earlier trials that one should have enough time to cross the crossing from the time when the warning was activated until the train arrived. Therefore, the subject had chosen to violate the crossing despite the warning of approaching train. Lower compliance rates were recorded for both passive devices, stop sign and rumble strips (74% and 72% respectively). In the non-complied categories of these passive devices, 16-17% had slowed down but nonetheless failed to stop while 10-11% drove through without reducing speed. The majority of subjects who failed to stop were from the 31-50 age group and equal in terms of the gender. Reasons given for the violations during the post-test interview were that no train was encountered, impatience and being unsure about the message conveyed by the passive signs.

Figure 5: Comparison of compliance behaviours towards different warning devices at 60km/hr in the driving simulator



Chi-squared tests were performed to compare the significance of compliance variation among the four different types of warning devices. First set of null hypotheses tested was:

H_o = there is no significant different in driver compliance between each individual type of warning device.

The compliance variation between *FL* and *IV* as well as between *RS* and *SS* was not statistically significant. On the other hand, the differences were statistically significant at the 99% confidence level between *FL* and *RS*; *IV* and *RS*; *FL* and *SS*; and *IV* and *SS*. In other words, driver compliance at passive crossings (*RS* and *SS*) are statistically different from active crossings (*FL* and *IV*), while differences in driver compliance are not significant within both passive and active crossings.

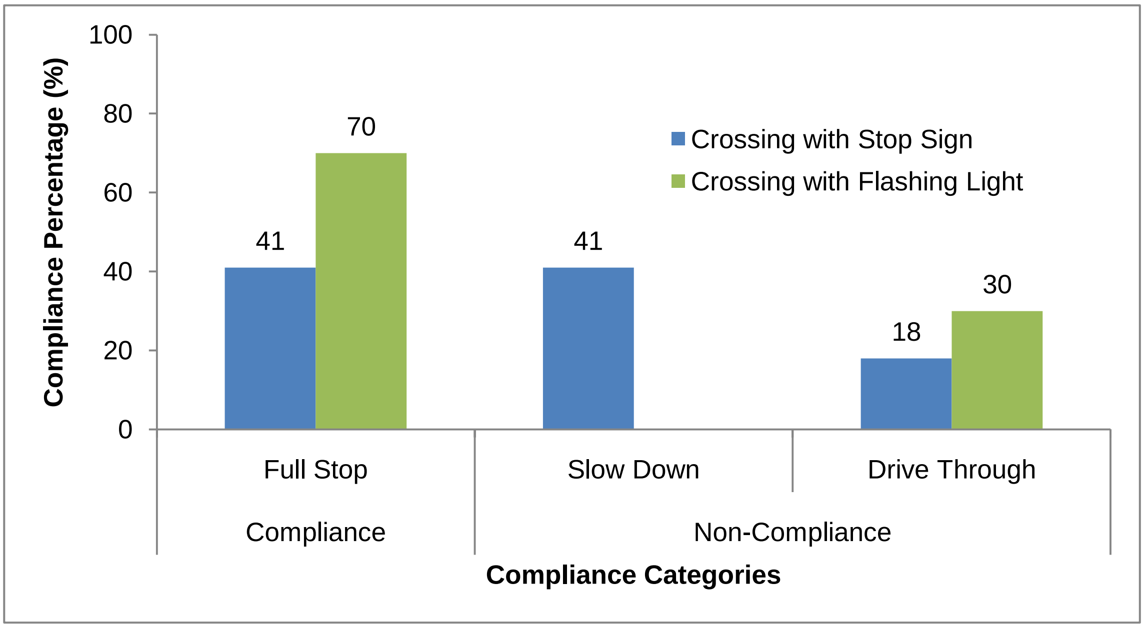
The second null hypothesis tested was:

H_o = there is no relationship between driver compliance and the types of protection systems.

In order to test the hypothesis, compliance data from the four types of warning devices were used in testing the relationship between driver compliance and types of warning devices. The Chi-squared test indicates that driver compliance at crossing is significantly influenced (at 99% confidence level) by the varying warning devices used.

The results from the simulated drives are consistent with field results shown in Figure 6. When comparing the controlling devices (stop sign and flashing-red-light) in the simulation experiment to actual field survey results at crossings with the same devices, passive crossing (stop sign) showed lower compliance rate than active crossing (flashing-red-light). The compliance percentages for both passive and active devices were higher in the simulated experiment by 33% and 30% respectively. This is expected since the simulation experiment had less contributing variables compared to those occurring in the actual field. Furthermore, some drivers in the simulation experiment might have had the mindset that they were being tested and thus did not react as they might normally do in the actual world. Nevertheless, the ratio of compliance percentage of passive to active devices in both simulated and actual environments were very close, 74:100 (0.74) and 41:70 (0.59), as shown in Figures 5 and 6 respectively.

Figure 6: Comparison of compliance behaviours at field crossings with ‘stop sign’ and ‘flashing-red-light’



4. Conclusions

Drivers approaching a RLX with a ‘stop sign’, either with or without rumble strips, are expected to obey the regulatory sign to stop the vehicle before the stop line regardless of the presence of a train. For active warning systems, either the ‘flashing light’ or ‘in-vehicle auditory warning’, drivers are required by the road rules to stop when the warning is activated by an approaching train. As expected, the road rules always give priority to the train at a crossing. However, the operational characteristics of these warning devices, for several reasons (i.e., passive/active, lack of train information, lack of attraction, etc.), ‘produce’ different driver responses. The driving simulator results presented here show that the compliance level at passive crossings is considerably lower than at active crossings. Although non-compliance at crossings was expected from the field survey and previous observational studies, it is surprising to observe a high non-compliance rate for passive crossings in the simulated experiment, given the fact that the participants were aware they were being ‘observed’. It is worth noting that non-compliance at passive crossings in a driving simulator was also found in a study in Victoria, Australia (Lenne et al., 2011). Rumble strips in some cases caused speed reduction at the early (approaching) stage, however, failed to produce net safety benefits in term of compliance at crossings. The 1% violation of the in-vehicle warning reveals that its design features need further investigation.

Comparison among the RLXs in terms of 'driver compliance', clearly indicates that drivers react differently to different warning devices, particularly the passive systems. The simulator results are consistence with the field results - on average there is less driver compliance for passive crossings than active ones. Although the alternative devices reveal similar driver compliance compared to the conventional ones, the considerably lower costs of application of the alternative systems compared to conventional active systems provide extra motivation for their use (Roop et al., 2005; Graham and Hogan, 2008). The Chi-squared test indicates that driver compliance at RLXs is significantly influenced (at 99% confidence level) by the varying warning devices used. A future stage of the current study will concentrate on incorporating these driver responses into a microscopic traffic simulation approach. The driving simulator experimental design can also be extended to testing the influence of other human factors such as distraction, fatigue, and familiarity at crossings to the driver responses towards various types of warning devices.

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References

Abraham, J., Datta, T. K. & Datta, S. (1998) Driver Behaviour at Rail-Highway Crossings. *Transportation Research Record: Journal of the Transportation Research Board,* 1648(1)**,** 28-34.

Australia Transport Safety Bureau (2010) ATSB Transport Safety Report: Rail Statistics. *Australian Rail Safety Occurrence Data 1 January 2001 to 31 December 2009.* Canberra, Australia, Australia Transport Safety Bureau.

Australian Transport Council (2010) National Railway Level Crossing Safety Strategy 2010-2020.

Bureau of Transport and Regional Economics (2002) Rail Accident Costs in Australia. Canberra, Australia, Bureau of Transport and Regional Economics.

Carlson, P. J. & Fitzpatrick, K. (1999) Violations at Gated Highway-Railroad Grade Crossings. *Transportation Research Record: Journal of the Transportation Research Board,* 1692(1)**,** 66-73.

English, G. & Murdock, J. (2005) Pilot Evaluation of Automated Grade Crossing Signal Enforcement. Quebec, Transportation Development Centre of Transport Canada.

Ford, G. & Matthews, A. (2002) Analysis of Australian Grade Crossing Accident Statistics. *Seventh International Symposium on Railroad-Highway Grade Crossing Research and Safety.* Melbourne, Monash University.

Graham, B. & Hogan, C. (2008) Low Cost Level Crossing Warning Device. Victoria, Sinclair Knight Merz and VicTrack Access.

Hirou, C. (1999) Crossing Signals Enforcement and Intrusion Detection. IN VESPA, S. (Ed.) *Workshop on Rail-Highway Grade Crossing Research.* Ottawa, Transport Canada.

Lenne, M. G., Rudin-Brown, C. M., Navarro, J., Edquist, J. & Trotter, M. (2011) Driver Behaviour at Rail Level Crossings: Responses to Flashing Lights, Traffic signals and Stop Signs in Simulated Rural Driving. *Applied Ergonomics,* 42**,** 548-554.

Meeker, F., Fox, D. & Weber, C. (1997) A Comparison of Driver Behavior at Railroad Grade Crossing with Two Different Protection Systems. *Accident Analysis and Prevention,* 29(1)**,** 11-16.

Roop, S. S., Roco, C. E., Olson, L. E. & Zimmer, R. A. (2005) An Analysis of Low-Cost Active Warning Devices For Highway-Rail Grade Crossings. Texas, Texas Transportation Institute.

Shinar, D. & Raz, S. (1982) Driver Response to Different Railroad Crossing Protection Systems. *Ergonomics,* 25(9)**,** 801-808.

Standards Australia (2009) Manual of Uniform Traffic Control Devices, Part 7: Railway Crossings. 3rd ed. Sydney, Australia, Standards Australia.

Tey, L. S. (2009) A Traffic Simulation Approach to Evaluating Cost-Effective Railway Level Crossing Protection Systems. *PhD Confirmation of Candidature Report.* Brisbane, University of Queensland.

Tey, L. S. & Ferreira, L. (2010) Driver Compliance at Railway Level Crossings. *33rd Australasian Transport Research Forum.* Canberra, Bureau of Infrastructure, Transport and Regional Economics and Australian Capital Territory Department of Territory and Municipal Services.

Tey, L. S., Ferreira, L. & Dia, H. (2009) Evaluating Cost-Effective Railway Level Crossing Protection Systems. *32nd Australasian Transport Research Forum.* Auckland, Ministry of Transport.

Transport and Main Roads (2010) Traffic and Road Use Management Manual - Volume 3: Road Safety. *Rumble Strips.* Department of Main Roads, Queensland Government.

Wigglesworth, E. C. & Uber, C. B. (1991) An Evaluation of the Railway Level Crossing Boom Barrier Program in Victoria, Australia. *Journal of Safety Research,* 22(3)**,** 133-140.