Measuring Driver Responses at Railway Level Crossings

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Abstract

Railway level crossings are amongst the most complex of road safety control systems, due to the conflicts between road vehicles and rail infrastructure, trains and train operations. Driver behaviour at railway crossings is the major collision factor. The main objective of the present paper was to evaluate the existing conventional warning devices in relation to driver behaviour. The common conventional warning devices in Australia are a stop sign (passive), flashing lights and a half boom-barrier with flashing lights (active). The data were collected using two approaches, namely: field video recordings at selected sites and a driving simulator in a laboratory. This paper describes and compares the driver response results from both the field survey and the driving simulator. The conclusion drawn is that different types of warning systems resulted in varying driver responses at crossings. The results showed that on average driver responses to passive crossings were poor when compared to active ones. The field results were consistent with the simulator results for the existing conventional warning devices and hence they may be used to calibrate the simulator for further evaluation of alternative warning systems.

Keywords:

Railway level crossing, warning devices, field video recording, driver compliance, approaching speed profile, final braking position

1. Introduction

Background

Railway level crossings create serious potential conflict points for collisions between road vehicles and trains. Safety at level crossings is a world-wide issue which increasingly attracts the attention of relevant transport authorities, the rail industry and the public. According to a report by the National Transportation Safety Board (1998), more than 2,000 accidents occurred at active and passive railway crossings in the United States each year from 2006 through 2010 (Federal Railroad Administration, 2011). Each year hundreds of people across Europe die in accidents at level crossings, which accounts for one third of all rail fatalities and 1-2% of all road deaths (European Commission, 2010). In Australia, during the years 2007 to 2009, there was an average of 55 collisions at crossings involving road vehicles each year (Australia Transport Safety Bureau, 2010). These accidents not only cause loss or injury of humans but also incur huge property and economic losses. The financial cost of collisions at crossings has been estimated at AUD$32M per year excluding rail operators and infrastructure losses (Australian Transport Council, 2003; Bureau of Transport and Regional Economics, 2002).

Level crossings are amongst the most complex of road safety issues, due to the addition of road vehicles with rail infrastructure, trains and train operations. The contributory factors to collisions at crossings can be difficult to determine and generally involve several factors for a particular incident. Nevertheless, in Europe, 95% of level crossing accidents are caused by road users (Woods, 2010). In 2008, there were around 2,000 accidents and almost 600 fatalities mainly due to users' misbehaviours (European Level Crossing Forum, 2011). In Australia, among the major collision factors are adverse weather or road conditions (13%), unintended motor vehicle driver error (46%), alcohol / drug use by motor vehicle driver (9%), excessive speed (of motor vehicle driver) (7%), fatigue (of motor vehicle driver) (3%) and other risk taking (of motor vehicle driver) (3%) (Australian Transport Safety Bureau, 2002). From these statistics, it is clear that human factors are the major cause of these accidents (total 68%).

There are approximately 9,400 public railway crossings in Australia. They are protected by either passive (64%) or by active or automated systems (28%) (Ford and Matthews, 2002). Passive crossings provide only a stationary sign regardless of approaching train to the crossing. Thus their message remains constant with time. Drivers approaching a crossing with a 'stop sign' are expected to obey the regulatory sign to stop the vehicle preceding the stop line and to look to the left and right for train traffic regardless of train presence. An active warning systems begins functioning with automatic warning devices (i.e., flashing lights, boom barrier, etc.) as it detects a train approaching. The active systems used in Australia comprise either a 'flashing light' or 'half boom barrier with a flashing light', which requires drivers to stop when the red light is activated by an approaching train. The differences in the operational characteristics of these systems together with the varying crossing geometry, traffic or/and train characteristics, form different driver behaviours at crossings. These driver behaviours subsequently become the major concerns to safety issues at crossings.

This paper is structured as follows: Section 1 summarises previous research, Section 2 provides a description of the methodology of data collection and analysis; Section 3 presents and compares the results from the field survey and driving simulator experiment and Section 4 presents the main findings and discusses future research.

Previous Research

As mentioned previously, different types of warning devices used at crossings significantly influence drivers' behaviour (Anandarao and Martland, 1998; Caird et al., 2002; Yeh and Multer, 2007). For instance, violations of warning devices have been detected in previous research. As part of Pickett and Grayson's (1996) study, 100 drivers were interviewed after being seen to cross level crossings when the red stop lights were flashing. Results from the interviews concluded that the majority of respondents showed an understanding of the operation of the crossings but an understanding of level crossing signals was on the whole poor compared with that of conventional road traffic signals. Results from another study conducted in New Jersey cities by Jeng (2005) suggested that some traffic control devices used in the vicinity of level crossings, such as a stop sign and traffic signal lights, could confuse drivers. Many drivers were not familiar with traffic control devices at crossings, which may have led to misjudgement of appropriate reactions at crossings.

Passive crossings show an increased likelihood of recognition errors by drivers because drivers may simply fail to see trains at these types of crossings. Active crossings dramatically reduce these kinds of recognition errors. Nevertheless, they produce other forms of driver behaviour error. For example, the level of automation can induce violation behaviour when drivers are required to wait for a lengthy period of time (Caird et al., 2002). Documented interviews with train drivers indicate many situations where motorists deliberately choose to ignore the crossing signs or signals, perhaps to minimise delays or inconvenience (Davey et al., 2005).

Drivers' age and gender have been identified as contributing factors to violation of road rules (Abraham et al., 1998; Davey et al., 2006; Parker et al., 1992), which in turn may be strongly related to collision likelihood. Potentially, violation can be used to evaluate system performance of varying warning devices. This parameter was adopted in some studies (Carlson and Fitzpatrick, 1999; Hirou, 1999; Meeker et al., 1997). Abraham et al. (1998) presented a possible association between violations of road rules and past crash histories at crossings.

While warning systems seem to affect the violation rate, how speed reduction patterns are influenced by the warning devices should also be investigated in order to better understand the efficiency of a particular system in attracting drivers' attention, respect and adherence. Although early detection of warning devices does not necessary result in safe adhering behaviour, it allows drivers to have adequate time to make decisions. Several studies have investigated the mean speed reduction at the approach way of level crossings (Ng and Saccomanno, 2010; Shinar and Raz, 1982; Ward and Wilde, 1995; Wilde et al., 1987). Moon and Coleman III (1999) have used drivers' speed selection as a direct element of behaviour in their study. They have suggested that the development of vehicular speed profiles is an important variable to be considered in characterising driver behaviour at crossings.

In addition to initial speed reduction on approach, final braking responses prior to stopping can also be obtained from a vehicular approaching speed profile towards a crossing. The activation position of final braking directly contributes to the collision/near-miss likelihood since the later the braking, the shorter the time-to-collision, hence the higher the possibility of a collision. It has been found that braking responses at road intersection are gender and age-related, similar to warning violation (Bao and Boyle, 2008; El-Shawarby et al., 2007). Nevertheless, relatively little research has been conducted specifically into drivers' braking position at level crossings in particular to the influence of various types of warning devices.

Other than driver characteristics such as age and gender, human factors like 'familiarity', 'distraction' and 'fatigue' are frequent reasons affecting driver behaviours. For instance, familiarity with a crossing can influence driver behaviour in a variety of ways. Wigglesworth (2001) noted in his Australian study that 85% of those killed lived locally and were familiar with the crossing. In the United Kingdom, Pickett and

Grayson (1996) also found that the majority of drivers who violated activated warning systems were regular users of the level crossings.

Since driver behaviour is one of the important contributing factors to the success of a particular warning system, this paper evaluates driver responses towards different conventional warning devices at railway crossings. The evaluation uses ‘stopping compliance’, ‘approaching speed profile’ and ‘final braking position’ to measure the responses. These measurements are direct parameters in determining the effectiveness of the systems in attracting driver’s attention and respect, and hence, are reflected in the results of their reactions. Nevertheless, research on the influence of some human factors (familiarity, distraction, fatigue, and so forth) on driver behaviour at crossings, in particular to varying types of warning devices, are difficult to conduct in the field as they may endanger or/and interrupt traffic operations. Due to this fact, the current study included a driving simulator as a tool to collect the same measurements of driver responses in laboratory as in the field video recording survey. Findings from the driving simulator were compared with the field results. It was hoped that if they correlated the driving simulator could be used for future research on alternative warning devices and influences of various human factors. By disaggregating the scenarios in an actual field setting and in a laboratory setting, this paper identified the impact of different conventional warning systems on driver behaviour.

2. Methodology

The data were collected using two approaches: field video recordings at selected sites and driving simulation in a laboratory.

2.1 Field video recording

<u>Setting up</u>

Data were collected using a portable traffic surveillance camera. A telescoping flag-pole of 1.5 to 5 m high was modified to hold the camera in order to attach it to a suitable support at the crossing site such as a traffic pole or tree. The selected study sites were carefully investigated so that the camera was installed in such a way that it was hidden from drivers' attention, which may have affected their driving behaviour. The camera was erected near the crossing to capture the operation of the warning devices as well as more than 200 m of roadway from the stop line as schematically shown in Figure 1. Once the recording process started, distance was measured using a 'distance measuring wheel'. Steel plates painted in white were placed at 20 m intervals from the stop line (referred as 0 m) until 200 m on both sides of the road. An enumerator then walked across the road at every interval as an indicator of the distances measured from the stop line. This process was recorded by the camera. The white steel plates were then removed from the site after the distance marking process was completed to avoid distracting the drivers' attention.

[Figure 1: Setting up of camera for field surveys]

Video footage was captured under normal daylight conditions from 6:00 a.m. to 5:30 p.m. at 25 video frames per second. Data were collected for all vehicle types including passenger vehicles, trucks, and buses. However, the major traffic composition was passenger vehicles. From the field observation during site selection trips, an approaching distance of 200 m was found to be sufficient for drivers of all vehicle types to react appropriately to the warning devices.

<u>Site selection</u>

One assumption was made here, and is perhaps true, that the driver responses observed at crossings were mainly attributed to the warning devices used. Hence, a criterion of site selection was to minimise other possible geometric distractions to drivers' attention such as side road in proximity of a crossing, road gradient, and poor visibility. The visibility to warning devices at all the sites was adequate. Posted speed limits at the study sites were within 60-70 km/hr. Based on the conditions of the sites selected, it is practicable to assume that the operational characteristic of the warning system was the main element influencing drivers' responses.

Crossings with three different types of existing conventional warning devices (stop sign, flashing lights and half boom barrier) currently in use in Australia were included in the current study for comparison of driver responses. For that purpose, three level crossings in or close to Brisbane in Queensland, Australia were selected. The first selected site, Site 1, is a passive crossing equipped with stop sign (as shown in Figure 2(a), (Standards Australia, 2009)). This crossing crosses a rural road at a 90 degree angle. The roadway is a two-lane two-way road that branches out from a major collector linking a few towns between Ipswich and Toowoomba. The crossing is located more than 1 km away from the major collector. The train track serves weekly passenger trains from Brisbane to Toowoomba and coal trains to the Port of Brisbane. Site 2, the second study site, is equipped with flashing red lights and a bell. The flashing red light signal (as shown in Figure 2(b), (Standards Australia, 2009)) consists of twin red circle lights arranged horizontally and equipped to flash alternately. This crossing crosses a major local street with one-lane in each traffic direction, at 90 degrees. The crossing is located approximately 400 m from an adjacent T-intersection. The train track mainly serves a holiday/tourism train and occasionally coal trains from Swanbank Power Station to the Port of Brisbane. The third crossing, Site 3, is equipped with flashing red lights, a bell and a half boom barrier (as shown in Figure 2(c), (Standards Australia, 2009)). As the warning system detects an approaching train, the flashing red signal is activated, followed 7-8 seconds later by the boom barrier, which starts to descend from the upright position to its horizontal position in approximately 8 seconds, blocking the traffic from entering the crossing on the appropriate side of the road. After the train passes the crossing, the boom barrier lifts gradually to its original vertical position in approximately 10-12 seconds; followed by deactivation of the flashing lights approximately 0-2 seconds later. The train track crosses a four-lane two-way local major street with a median barrier at 45 degrees. The crossing is located approximately 500 m from an adjacent signalised T-intersection. The train track is part of the daily Brisbane city passenger train network.

[Figure 2: (a) Stop sign; (b) Flashing lights; and (c) Half boom barrier]

Table 1 summarises the crossing characteristics, traffic and train volume for the three sites. Data from Sites 1 and 2 were collected at two and three days respectively, in order to obtain adequate sample size due to the low traffic volume at Site 1 and low exposure rate to oncoming trains at Site 2. Only one day was allocated for data collection at Site 3 since there was high traffic and train volume.

[Table 1: Specific characteristics of selected study sites]

2.2 Driving simulator

Twenty-four volunteer drivers aged 17 to 66 years were recruited from the local community and university population to participate in a driving experiment in the Perception and Motor Systems Laboratory at The University of Queensland. The experiment was conducted in a fixed-base driving simulator. 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 virtual environment simulation which included level crossings with different warning devices was developed. After approximately 1.5 km of driving, the driver approached a level crossing. All level crossings that drivers encountered during the scenarios had the same road characteristics but different types of warning devices appeared randomly at the crossings. Two of the conventional warning devices (stop sign and flashing red-lights) were included for comparison with results from the afore-mentioned field video recording survey. A controlling computer acquired position data at each frame (time step). The details of the experiment setup are referred to in Tey et al. (2011).

2.3 Data analysis

From the field video recording survey, the time was encoded on each video frame and distances marked during the recording (intervals of 200 m, 100 m, 80 m, 60 m 40 m, 20 m, 10 m and 0 m from the stop line or landmarks) were indicated on transparent sheets. The primary data retrieved were:

1) The ‘stopping compliance’ of every vehicle to the warning devices. For Site 1 with a stop sign, three categories of responses were observed: the vehicle stopped (compliance), slowed down but did not stop (non-compliance) or drove through the crossing neither slowing down nor stopping (non-compliance). For Site 2 with flashing lights, two categories were recorded: the vehicle stopped (compliance) or drove through (non-compliance). These two categories were also recorded for Site 3 after warning devices had been activated. In addition for Site 3, the compliance of the vehicles was noted after the warning devices had been deactivated. The compliance behaviours were categorised into three groups, namely: the vehicle started to move after both the boom barrier and the flashing lights were deactivated (compliance), after the boom barrier but before the flashing lights had deactivated (non-compliance), or before both the boom barrier and the flashing lights had deactivated (non-compliance).
2) The ‘approaching speed profile’ of the ‘subject’ as it approached and stopped at the crossings. The ‘subject’ refers to the first vehicle approaching the crossing from more than 200 m that was uninhibited by other vehicles after the warning devices had been activated. The times when the warning device was activated and subject reached the distance intervals indicated were recorded. From this data, the ‘approaching speed profile’ was derived of vehicle speed from the plots of distance as a function of time.
3) The ‘final braking position’ of each subject was analysed from its ‘speed profile’. ‘Final braking position’ is defined as the point where the driver completed braking prior to stopping at the stop line. Thus, the point where the final abrupt speed reduction inspected prior to the stop line (distance referred to as 0 m) was determined from the speed profile plot.

From the driving simulator experiment, data on ‘stopping compliance’, ‘approaching speed profile’ and ‘final braking position’ were retrieved directly from the vehicle trajectories records in the controlling computer.

3. Results and discussion

Despite the small sample size, significant results were obtained as discussed in this section.

3.1 Stopping compliance

<u>Field results</u>

From the video recordings, data on 66 (Site 1), 27 (Site 2) and 204 (Site 3) vehicles were analysed. Figure 3 shows the comparison of compliance behaviour of drivers approaching the crossings at Sites 1 (stop sign), 2 (flashing lights) and 3 (boom barrier and flashing lights). For Sites 2 and 3, the non-compliance category of 'Slow Down' was not existent because no speed reduction was observed with non-compliant behaviour. The compliance percentage for passive crossings (41%) was considerably lower than for the active crossings (70% and 77% respectively). Chi-squared tests (contingency table technique) performed indicate that driver compliance at passive crossings were statistically different at the 99% confidence level from active crossings (between Sites 1 and 2, χ^2=6.65; between Sites 1 and 3, χ^2=29.86), while differences in driver compliance were not significant within active crossings (between Sites 2 and 3, χ^2=0.57). Such an observation was expected, given the greater prominence of train approach of active systems. Ignoring a stop sign at a crossing may ultimately lead to a collision with a train, as drivers have been found to be unable to accurately judge the speed and distance of an oncoming train (Cohn and Nguyen, 2003; Cooper and Ragland, 2008)

Similar to results reported by various other studies (Carlson and Fitzpatrick, 1999; Meeker et al., 1997; Shinar and Raz, 1982), the compliance rate with boom barrier (77%) is slightly higher than with flashing lights (70%), as shown in Figure 3; although Abraham et al. (1998) found the opposite with drivers tending to commit more violations at gated level crossings compared to those with only flashing lights. These differences are thought to exist due to different localised site conditions, driver behaviour and other environmental conditions. Additionally, it was found that drivers tended to be more cautious at passive crossings (18%) than at active ones (30% and 23% for flashing lights and boom barrier and flashing lights respectively). This scenario is likely to occur because drivers' are scanning for train information at passive crossings whereas this information is readily available at active crossings.

Some reasons for non-compliant behaviours were reported in previous studies such as driver familiarity with particular level crossings (Abraham et al., 1998; Caird et al., 2002; Pickett and Grayson, 1996; Wallace, 2008; Wigglesworth, 1979), traffic control devices used (Abraham et al., 1998; Jeng, 2005; Smith, 2004), and drivers' intentional action or/and unintended error (Anandarao and Martland, 1998; Caird et al., 2002; Cairney, 2003; Davey et al., 2007; Pickett and Grayson, 1996; Wigglesworth, 2001; Witte and Donohue, 2000).

[Figure 3: Comparison of compliance behaviours at Sites 1, 2 and 3]

Inspection of the video at Site 3 identified the compliant behaviours of 157 of the 204 vehicles after the warning devices had been deactivated. Once the train was detected leaving the crossing, the warning devices would be deactivated, first by lifting the boom barrier to its vertical position taking approximately 10-12 seconds, followed by stopping the flashing lights 0-2 seconds later. Vehicles were permitted to navigate the crossing after both the boom barrier and flashing lights had been deactivated. Thus, vehicles waiting at the crossing were investigated for their compliance with the warning devices and categorised into 'Compliance' (moved after both the boom barrier and flashing lights were deactivated), 'Boom-gate' (moved before the boom barrier fully lifted) or 'Flashing Light' (moved after the boom barrier fully lifted but before the lights stop flashing). This scenario was investigated because it is important for 'second train collisions'. Figure 4 shows that more than one-third of the drivers ignored the operation of the warning devices. These violations indicated that the possibility of intentional action rather than unintended error was high.

[Figure 4: Compliance behaviour after warning devices deactivated at Site 3]

<u>Experimental results from the driving simulator</u>

The results from the driving simulator in the laboratory (Figure 5) were consistent with the field results (Figure 3): passive crossings (stop sign) showed a lower compliance rate (74%) than active crossings (flashing-red-lights) (100%). 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. The ratio of compliance percentage of passive to active devices in both simulated and actual environments were considerably close, 74:100 (0.74) (Figure 5) and 41:70 (0.59) (Figure 3) respectively. 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).

[Figure 5: Comparison of compliance behaviours in driving simulator with 'stop sign' and 'flashing-red-light']

3.2 Approaching speed profile

<u>Field results</u>

There was no speed reduction observed for the non-compliant vehicles. Typical speed profiles for each of the sites are shown in Figure 6. Overall, the vehicle's speed decreased as it approached the crossing. Similar results were observed in Moon and Coleman III's (1999) study, with their results indicating that there was a tendency for vehicles to reduce speed from the approach way to the track zone when a single vehicle was approaching the crossing. In Figure 6, the speed profile of Site 1 (stop sign) shows more obvious speed changes nearer to the stop line as compared to the smoother speed profiles of Sites 2 (flashing lights) and 3 (boom barrier and flashing lights). At Sites 2 and 3, drivers reacted more quickly and, as a result, slowed down more gradually. This may be due to the lack of prior warning of a stop sign in attracting drivers' line of sight as compared to flashing lights and a boom barrier which allow drivers to observe the flashing lights from further away, thus having more time to react to the stimulus. These results support Shinar and Raz's (1982) findings that when drivers were given the opportunity to utilise information provided by the different warning systems while they are still quite distant from the crossing, they produced a smoother speed profile. This situation may possibly lead to a shorter time-to-collision at passive crossings and hence, a higher probability of a collision with a train. Although some may argue that restricted visibility (e.g. vegetation) influences the speed reduction behaviour, Ward and Wilde (1996) found in their study that improvement of lateral sight distances at passive crossings resulted in an upward shift to longer search times but a tendency towards faster approach speeds, and thus failed to produce a calculated net safety benefit. This finding again confirms how important the choice of a warning device type affects driver behaviour at crossings.

[Figure 6: Field results comparing typical speed profiles recorded at Sites 1, 2 and 3]

Experimental results from the driving simulator

The comparison of typical speed profiles of the two conventional warning devices (stop sign and flashing lights) are presented in Figure 7 for the designated speed of 60 km/hr. Overall, vehicle speed decreased as it approaching the crossing. The speed profile for the flashing-red-lights was smoother compared to the stop-sign where more obvious speed changes were observed nearer to the stop line. This pattern is consistent with the field results shown in Figure 6. The speed reduction profiles established can be used to model driver behaviour in traffic simulation models.

[Figure 7: Comparison of typical speed profiles recorded in the driving simulator]

3.3 Final braking position

Field results

The distributions of 'final braking positions' for Sites 1, 2 and 3 are shown in the box-and-whisker plot in Figure 8. It clearly indicates that the majority of drivers at Site 1 reacted nearer to the crossing as compared to Sites 2 and 3. The box plot shows a box encased by two outer lines known as 'whiskers'. The box contains the middle 50% of the data sample – the bottom and top of the box are the 25th and 75th percentile (the lower and upper quartiles) respectively. The single line inside the box represents the median. The remaining 50% of the sample is contained within the areas between the box and the whiskers. Also shown in Figure 8 are the mean, skewness of the sample and the kurtosis. Results from Site 1 are normally distributed because the median line is located near the centre of the box and the box is nearly centred between the whiskers. The lower (13 m) and upper (20 m) quartiles indicate that middle half of the drivers observed reacted in this zone. All data were contained within the whiskers (-1.5*interquartile range to +1.5*interquartile range) without any extreme cases (outliers).

Results from Site 2 are positively skewed as the box is shifted significantly to the lower end. The lower (21.5 m) and upper (32 m) quartiles indicate that the middle half of the drivers observed reacted in this zone. All data were contained within the whiskers without any extreme values except for two cases (both 48 m) that were slightly above the maximum (+1.5*interquartile range) value of 47.8 m. Results from Site 3 are similar to Site 2 except that the distribution of data is more widely spread and the maximum value (60.9 m) is further from the stop line. The results are positively skewed as the box is shifted significantly to the lower end. The lower (21.5 m) and upper (37.3 m) quartiles indicate that the middle half of the drivers observed reacted in this zone. All data were contained within the whiskers without any extreme cases except for one value (61 m) that was slightly above the maximum value of 60.9 m. Comparatively, mean ‘final braking positions’ at Site 1 with a stop sign (16.5 m) are nearer to the stop line than at Sites 2 (28.5 m) and 3 (30 m) with active systems. Many drivers at Site 2 and particularly at Site 3 reacted much earlier when train approach information (warning devices activated) was available, although the mean and median values were close to the stop line. Some statistical values of ‘final braking positions’ for Sites 1, 2 and 3 are tabulated in Table 2.

[Figure 8: Comparison of ‘final braking positions’ recorded at Sites 1, 2 and 3]

[Table 2: Summary of ‘final braking positions’ comparison of Sites 1, 2 and 3]

<u>Experimental results from the driving simulator</u>

The mean ‘final braking positions’ results from the simulated experiment were 21 m and 36.9 m for the stop sign and flashing lights respectively. These are consistent with the field results: passive crossing (stop sign) showed ‘final braking positions’ closer to the crossing than for active crossings (flashing-red-lights). The average ‘final braking positions’ for the stop sign and flashing-red-lights was higher in the simulated experiment than in the field results (4.5 m and 8.4 m respectively). The driving simulator results of ‘final braking positions’ were 1.3 times higher than the field results for both stop sign (21÷16.5=1.3) and flashing-red-lights (36.9÷28.5=1.3). Evaluation of the different warning systems in the field and in the laboratory shows that the average ‘final braking position’ at passive crossings is half that of active crossings.

4. Conclusions

Driver behaviours are important in determining candidate warning systems for railway crossings. The results of this paper reveal the weaknesses of the passive warning system in obtaining drivers’ respect in compliance and slower reaction to reduce speed. While within active systems the response differences between flashing lights and the boom barrier are small, the boom barrier produces a slightly higher percentage of compliant behaviour and earlier braking. This clearly indicates that drivers behave differently to different warning systems, particularly to the passive system which is commonly used in rural areas. Based on the results of the current study, it is concluded that on average driver responses to passive crossings are poor compared to active crossings. This conclusion is consistent with previous observational studies that found compliance at stop signs at crossings was low (Lerner et al., 1990; National Transportation Safety Board, 1998). A study in 1978 highlighted the fact that the majority of drivers did not search for trains at passive crossings which revealed the failure of passive warnings (Wigglesworth, 1978). One of the key suggestions to reduce the risk of accidents at passive crossings was to make warning devices (traffic signs) more conspicuous (Russell et al., 1999; Ward and Wilde, 1995). Nevertheless, Stackhouse (1996) found no evidence suggesting that bigger and/or brighter or other modifications of traditional signs and/or signals led to favourable changes in drivers' behaviour at crossings. In Sweden, an observational study by Aberg (1988) showed that many drivers turned their heads to look for trains although the crossings were equipped with flashing warning lights. He found no reason for this. However, upgrading passive crossings to active ones still seems worthwhile.

The evidence from the current study and from previous research in Australia, shows that installation of active systems at crossings provides substantial safety benefits. However, to upgrade all the passive crossings with automatic systems involves a huge investment while the feasibility is questionable since collisions occur randomly with significant variations in time and space. Furthermore, recent crossing collision records have revealed that 50% of vehicle collisions at crossings happen at actively controlled crossings (Australian Transport Council, 2003). These collisions are reported to be mainly attributed to driver behaviours in response to the warning systems (Australian Transport Council, 2003; Chartier, 2000; Wallace et al., 2008). These situations raise the question of whether upgrading crossings from passive to active is a real solution for safety at crossings, considering the cost incurred and the system effectiveness gained. In view of that, searching for new cost-effective technologies or devices is compelling.

Considerable research and innovation has occurred in some countries on low-cost warning systems for crossing safety. For instance, several researchers found that installation of rumble strips resulted in speed reduction (Gates et al., 2008; Gorrill, 2007; Hore-Lacy, 2008; Radalj and Kidd, 2005; Thompson et al., 2006). In addition, in-vehicle technologies such as in-vehicle warning systems are a potential intelligent transportation system countermeasure that provide warning of train presence to motorists via visual and/or audio warnings in their vehicles. Porter et al. (2008) encountered faster brake response times with the presence of an in-vehicle auditory alert in their simulated driving experiments. The considerably lower costs of application of some of these systems compared to conventional active systems provide extra motivation for their use (Graham and Hogan, 2008; Roop et al., 2005). There are opportunities for immediate application of some low-cost innovative systems subject to their effectiveness and adaptation to Australian conditions. Thus, the effectiveness of these alternative systems in influencing local driver behaviour needs to be assessed. However, there are challenges to test them in the field since these devices are not yet common/in use in the traffic network. Here, the use of a driving simulator allows evaluation of driver behaviour towards these innovative warning devices at crossings with current conventional devices included as control samples.

Comparison of driver responses in terms of 'stopping compliance', 'approaching speed profile' and 'final braking position' in this current paper has produced a better understanding of their responses towards existing conventional warning systems at railway crossings. In turn, these results have provided a more accurate comparison of driver responses at crossings in the field and of those obtained using a driving simulator. As the driving simulator provided similar results to the field data, their future use investigating the influence of human factors (i.e., age, gender, distraction, use of mobile phone, fatigue) to drivers' responses to new devices can be designed. Future research by the authors will concentrate on evaluating driver responses to alternative systems at crossings using a driving simulator. Improving level crossing safety by examining the drivers' responses to alternative systems is paramount. This future work will endeavour to answer the most fundamental research question in level crossing safety– *how can safe driving responses be elicited from motorists to best protect them against the risks associated with approaching trains at level crossings?* It has the potential to not only save lives but reduce the socioeconomic costs of vehicle-train collisions.

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