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Evaluating ITS interventions at railway level crossings using a driving simulator

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Abstract

This paper assesses Intelligent Transportation Systems (ITS) to identify safety systems that are most likely to reduce driver errors at railway crossings. ITS technologies have been integrated in order to develop improved evaluation tools to reduce crashes at railway crossings. Although emerging technologies, knowledge, innovative interventions have been introduced to change driver behaviour, there is a lack of research on the impact of integrating ITS technologies and transportation simulation on drivers. The outcomes of ITS technologies for complementing traditional signage were compared with those of current safety systems (passive and active) at railway crossings. Three ITS technologies are compared with current treatments, in terms of compliance rate and vehicle speed profiles. It is found that ITS technologies improve compliance rate by 17~30% and also encourage drivers to slow down earlier compared to current passive and active crossings when there is a train approaching the railway crossings.

1. Introduction

It is very important to install safety systems that adhere to specific guidelines. This will help drivers make good decisions effectively and appropriately. Despite the fact that many railway crossing treatments have been introduced, few studies have been conducted to evaluate which alternative safety system is the most cost effective. Most crash models regarding railway crossings are based on historical records which are input of statistical models. There has been no methodology using driving simulator with the aim of identifying how safe a specific system is. In addition, driving simulator-based studies have not been used widely to cope with crossing collision causes.

In Australia (New South Wales excluded), 345 fatalities and 937 serious personal injuries resulted from train related incidents reported between 2001 and 2011. The number of road vehicle collisions at the railway crossings has decreased. This is due mainly to the implementation of high level of safety systems such as warning sounds, flashing lights and boom gates. However, there were still 48 crossing related vehicle-train collisions in 2011(Australian Transport Safety Bureau 2012). To prevent collisions, the government needs to allocate its annual budget for active protection systems at AUD$150,000 ~ AUD$300,000 per railway crossing. Annual maintenance and operating costs should also be taken into account (WestNet Rail and Australia Western Railroad 2002).

According to Queensland Rail (2012), there were 472 near misses at Queensland Rail level crossings in 2011. When trains narrowly avoid hitting motorists or vehicles but have a high potential to do so, it is called a “near miss”. The marginal difference between a near miss and a collision is merely a matter of luck. Therefore, the greater number of near misses there are, the higher the chances of collisions there are. A near miss contains a high possibility for injury, fatality or damage, which can consequently threaten people near railway crossings.

There were 48 collisions in Queensland in 2011. Among 472 near misses, there were 68 cases of driver misjudged, completely missed and starting against signal were recorded. Warning recognition is the most important element of which collisions are most likely to happen at passive crossings. Witte and Donohue (2000) point to three major reasons that people ignore warnings, namely: errors in judgement, sensation seeking tendencies and lack of personal experience. While the last two reasons rely on a driver's intention, errors in judgement can be reduced or eliminated by providing appropriate warning methods so that drivers can pay attention to potential danger sooner. Errors in judgement are well known to be unintentional errors that appear where drivers fail to notice warnings although the warnings operate well without any constraints (Lenné MG 2009). In Australia, this type of error contributes to almost 50% of fatalities on railway crossings compared to 22% of all other fatal crashes (ATSB 2002) . Salmon et al. (2013) concluded that unintentional errors caused by driving behaviours are much more likely to lead to collisions at railway crossings than other factors, such as the use of mobile phones, the influence of alcohol, drugs and fatigue. Information perception and processing are parts of unintentional errors. Unintentional errors can cause driver misjudgement, drivers completely missing signals and starting against the signals.

Moreover, out of 9400 public railway crossings in Australia, approximately 64% of them are passive crossings (Ford and Matthews 2002). A passive crossing consists of a simple stop sign where as an active crossing has different types of physical warnings such as flashing lights, boom barriers, or sounds. Since the chance of collisions depends greatly on a driver's intention to heed warnings, there are more collisions at passive crossings than active crossings (Tey et al. 2011). As passive crossings have been upgraded to active crossings in many countries, the number of collisions at railway crossings has decreased. However, upgrading railway crossings is very costly. Therefore, the use of ITS technologies has gained attention.

In the present study, 3 ITS devices, namely; visual, audio, and on-road flashing makers at both active and passive crossings were investigated using a driving simulator. Behaviour outputs were extracted to evaluate a different type of safety devices as well as performed by a statistical analysis to find significance of difference in approaching speed.

This paper is structured as follows: Section 2 reviews the use of driving simulators at railway crossings; Section 3 provides a brief description of the procedure use, as well as the base and three ITS interventions tested here. Section 4 presents compliance rates, vehicle speed profiles, statistical analysis and compares the results against a base case safety device. Section 5 admits limitations of this study. Finally, the main findings are discussed in Section 6.

2. Past work

Collecting real field data is the best way to analyse different driving behaviour as a basis of comparing different safety devices. However, the number of events in which a train and a vehicle can collide is very low. The use of a driving simulator is a good alternative for creating as many events as possible in order to obtain reliable data in a safe manner (Lenné et al. 2011).

There has recently been some research on driving behaviour at railway crossings using driving simulators in Australia. For example, Tey et al. (2011) compared driving behaviours between field data and driving simulator in terms of compliance rate, speed profile, and final braking position at railway crossings equipped with stop signs, flashing lights, and half boom barriers. Although they did not perform a statistical analysis to identify the significance of difference in component against different types of crossings, distributions of approaching speed, driver reaction and compliance behaviour for each crossing have been well described.

However, in another recent study Tey et al. (2013), used a fixed driving simulator, four different warning devices such as flashing lights, in-vehicle warnings, rumble strips, and stop signs were tested to identify compliance rates, driver accelerator release position, initial/final braking position. Unlike the previous study, they implemented a binary logistic regression model for predicting the probability of a driver stopping as well as mixed regression models for predicting drivers' reaction position. Age, gender, speed, and types of warning devices were major contributing factors to show significance at different approach stages to the level crossings.

According to Lenné et al. (2011), traffic signals can play a role in providing more adequate warning to drivers than flashing red lights by comparing railway crossings equipped with stop signs, flashing lights, and traffic lights in a moving driving simulator. Rudin-Brown et al. (2012) compared the effectiveness of traffic light and boom barrier controls at rail way crossings. Their results revealed that traffic lights are not superior to flashing lights with boom barriers in terms of safety benefit.

3. Experiment set-up

3.1 Apparatus and stimuli

The results reported here use experimentation conducted on the advanced driving simulator set up at the Centre for Accident and Road Research –in Queensland (CARRS-Q'). This simulator is composed of a complete automatic Holden Commodore vehicle with working controls and instruments. The advanced driving simulator uses SCANeR™studio software with eight computers, projectors and a six degree of freedom (6DOF) motion platform that can move and twist in three dimensions. When seated in the simulator vehicle, the driver is immersed in a virtual environment which includes a 180 degree front field of view composed of three screens, simulated rear view mirror images on LCD screens, surround sound for engine and environment noise, real car cabin and simulated vehicle motion (see Figure 1). The road and environment are developed to respect Australian Standards at RLXs, as well as create realistic traffic around the driven car. The rendering capabilities of this simulator enable it to display a realistic driving environment (highway, country road, Brisbane city). In order to produce a realistic scenario, SCANeR™can be programmed to control all the elements of the environment (point of view, vehicles, trains, pedestrians, trees, buildings, road signs, lights, etc.) in advance of or after specific events.

Figure 1 Driving simulator at Carrs-Q

This driving simulator is composed of a variety of modules working in coordination. Each module is responsible for one part of the simulation. Modules include:

- An application to choice of road network, creation of traffic, weather conditions);
- A module managing the physics (dynamics) of the driven and/or automated vehicles;
- A module to manage traffic;
- A visual module displaying the simulation on the screen;
- A sound module
- A motion module
- An acquisition module to obtain data from the car.

Users can also create their own modules to include such things as synchronising or triggering particular sensors.

SCANeR™ also enables one to create realistic road networks with a combination of straight and curvy sections, including intersections. It is possible to use satellite imagery or road maps to design the network and altitude can be modelled in the second step. SCANeR™ also contains a database of static environments such as buildings, signage, vehicles, pedestrians, trees and ground textures.

The participant sits in the driver's seat of the car. They can see three screens where the SCANeR™ simulation is projected by three RGB video projectors. The participant drives the simulator with two pedals (brake and accelerator only) and a steering wheel which provides force feedback.

3.2 Road network design

The road map used was of the Brisbane CBD (no RLXs), as well as a road network around it which presents an important number of RLXs.

Table 1 describes each crossing in terms of protection (active or passive), visibility (through curved or straight road sections before the crossing), as well as the direction of the curve for low visibility crossings.

Table 1 Characteristics of the RLX of the road network

RLX	Protection	Approach road	Direction
RLX 1	passive	curved	right
RLX 2	passive	curved	left
RLX 3	active	straight	-
RLX 4	active	straight	-
RLX 5	passive	straight	-
RLX 6	active	curved	left
RLX 7	active	curved	right
RLX 8	active	straight	-
RLX 9	active	straight	-

The itineraries were automatically generated by a program which extracted 8 crossings per itinerary according to the specifications outlined above. There are two types of crossing protection, two types of visibility at the crossing and two types of train approach/absence at crossings, which leads 8 different crossings. The case of no train presence, straight, and active was excluded in this study as this setting was used for different scenario. The program also computes cost of the itinerary from the estimated time cost required to go from one particular crossing to the next (based on the distance between crossings). Itineraries with the lowest cost are selected in order to minimise the time participants spend in the driving simulator.

20 itineraries with the lowest cost were selected following these requirements:

- The lowest cost is given priority
- Itineraries with similar sequences of railway crossings, as previously selected crossings are not selected.

In each drive, a subject encountered eight railway crossings equipped with different warning devices; a passive crossing and an active crossing. A single stop sign represented the passive crossing while flashing lights represented the active crossing. On each drive route, there were two different speed sign posts; 60 or 80 km/h, giving drivers a real world feeling. Each participant had 2 drives for base cases and one of three ITS devices for another drive.

3.3 Participants

Thirty drivers were selected to participate in this experiment ranging in age from 19 to 59 with a mixture of males (21) and females (9). All participants possessed driving licences and had various driving experience. Drivers were briefed about this research before they started a demographic survey and driving. Participants had four drives including one practice drive where drivers can get used to feeling of acceleration, brake, steering, and visualization, and three actual research drives. Drivers encountered that the warning was activated 6 seconds before they have reached the RLX when there was a train

3.4 Design of ITS interventions

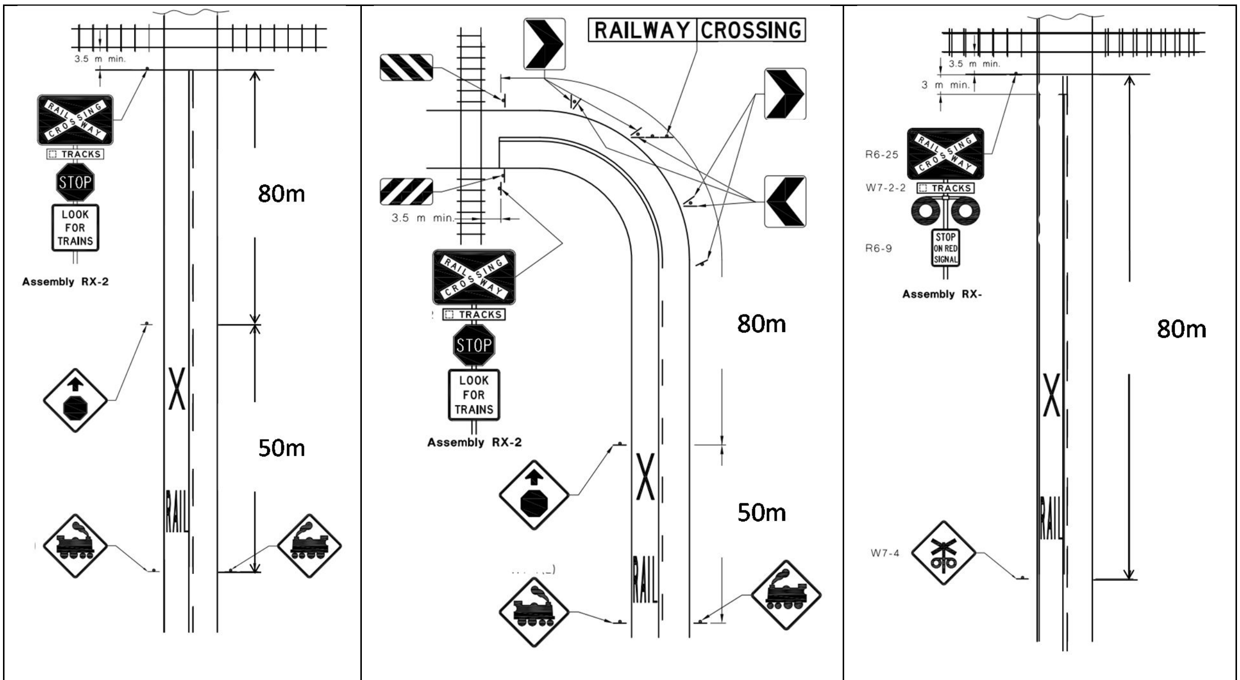
3.4.1 Base (Signage): Australian Standards

Signage at crossing was designed to follow Australian standards. In this experiment, passive crossings and active crossings without barriers were implemented. The following crossings were used in this experiment:

- Passive crossings with straight approach controlled by a stop sign
- Passive crossings controlled by a stop sign preceded by a curve
- Active crossing with straight approach controlled by flashing lights
- Active crossing controlled by flashing lights preceded by a curve

The first three types of crossings follow Australian standards and details of their geometry and required signage are detailed in Figure 2 Australia standard crossings (Transport and Main Roads 2009)

The last type of crossing is an experimental manipulation to model reduced visibility at crossings and does not follow Australian standards. It will be created by combining the requirements presented in Figure 2 Australia standard crossings (Transport and Main Roads 2009)



Passive crossing		Active crossing
Straight	Curve	Straight

Figure 2 Australia standard crossings (Transport and Main Roads 2009)

3.4.2 Visual ITS (ITS1)

The visual in-vehicle ITS was implemented with a smart phone. This smart phone was positioned within the driving cabin at the usual location of a GPS unit.

As a train approached the crossing, the smart phone displayed a warning flashing picture synchronised with the flashing lights of active crossings. For passive crossings the warning was displayed at an equivalent time. In this situation (train approaching), the warning provided two messages at the same time in one symbolic representation: the fact that a train was approaching the crossing and that the driver was expected to stop. Both pictures were displayed alternatively to make the lights flash as traditional signals did at active crossings. They were designed as a combination of the assemblies RX-2 and RX-5 in order to present both explanation and action messages to the driver.

This ITS was implemented with the simulator and the smart phone. When a particular status was reached, the appropriate action was sent to the smart phone.

The rendering of the implementation of the visual in-road ITS is shown in Figure 3.

Figure 3 Capture of the in-vehicle visual ITS (train approaching and congestion)

3.4.3 Audio ITS (ITS2)

The audio in-vehicle ITS used the speakers of the simulator positioned inside the car to provide warning messages to the driver.

As a train approached a crossing, the speakers provided a verbal warning as the flashing lights of active crossings was activated. For passive crossings the warning was provided at an equivalent time. In this situation (train approaching), two messages were given to the driver as in the visual ITS presented before:

- “Train approaching the crossing ahead”
- “Stop at the crossing”.

This ITS was fully implemented with the simulator and the messages were played as the status of the crossing changes and required a particular warning.

3.4.4 On-road flashing markers (ITS3)

This road-based ITS used flashing warning beacons on the road which were activated when a train approached a crossing. These beacons highlight the location where the driver was expected to stop their vehicle. This system improved driver awareness of the crossing status earlier and more conspicuously, even in the case of reduced visibility. .

Flashing markers on the road were activated at the same time as the flashing lights of an active crossing and were positioned up to 150 metres from the crossing. In the case of passive crossings, the lights were activated 20 seconds prior to the arrival of a train, which provided a similar time for the driver to react to the warning. Three in-road red lights were used to emphasise the stop line at the crossing. Five in-road yellow lights were positioned in the middle of the road every 6 metres, and a further ten in-road yellow lights were positioned every 12 metres.

Each individual flashing beacon was designed followed by Australian Standards reflective road.

This ITS was fully implemented with the simulator and is shown in Figure 4

Figure 4 Simulator rendering of the on-road ITS

4. Results

4.1 Compliance rates

For a stop sign, drivers must stop before reaching the stop line whether or not a train is approaching. The drivers must give way to a train which has approached the railway crossing. Flashing lights are used to notify drivers if a train is approaching the railway crossing. In the case where flashing lights are activated, the drivers go through as if they passing through a normal intersection with green lights.

Driver stopping compliance at crossings equipped with different warning devices was recorded. The cases in this study were train presence × crossing type (active or passive) × geometry (straight or curb) × device type (base, ITS1, ITS2, or ITS3).

Compliance behaviour is categorized as:

1. In case of train presence,
   1.1 In case of passive: Drivers stop completely.
   1.2 In case of active: Drivers remain stopped until flashing lights deactivate
2. In case of train non-presence,
   2.1 In case of passive: Drivers stop completely.

Table 2 shows compliance rates of drivers collected from the driving simulator. In the case of a passive crossing with train presence, the compliance rate is relatively low. It is worse when road geometry is a curve where drivers cannot reduce speed properly at the crossing at 71%, 88%, 90% and 100% for base, ITS1, ITS2, and ITS3, respectively. For active crossings, drivers have better braking by 17% ~ 30% because visibility of railway crossings is clearer than passive crossings.

When there was no train approaching, drivers looked around to check whether a train was approaching far away from the stop line. When they did not see a train some drivers seldom

slowed down. As ITS devices are regarded as complementary, drivers still need to obey traffic regulations as they drive through crossings without ITS devices. It is sought that drivers trust that active crossings and ITS devices are highly reliable.
Drivers traveling on a straight road obeyed almost 100% of traffic rules regardless of train existence for all devices.

Table 2 Compliance Rates (%)

Train	Type	Geo	Base	ITS1	ITS2	ITS3
Yes	Passive	Curb	71	88	90	100
		Straight	80	89	100	100
	Active	Curb	88	100	100	100
		Straight	92	100	100	100
No	Passive	Curb	75	44	60	56
		Straight	84	70	60	67

Note: ITS1:Visual, ITS2:Audio, and ITS3:On-raod flashing markers

4.2 Vehicle speed profiles

Approach speed profiles for drivers for many different situations are plotted I Figures 5 and 6. The X-axis represents 'Distance to Stop' in meters from 200m to 0 m, while the Y-axis presents 'Speed' in Km/h. Overall, speed drops from approximately 50m away from stop line. When it comes to comparison between base and ITS3 at active crossings with train approaching, drivers equipped with ITS3 keep a lower speed for entire distance and react to warnings earlier. Without ITS intervention, from 200m up to approximately 75m the maximum vehicle speeds remain over 70km/h while with ITS3, the maximum speeds are nearly 60km/h. The speed variations at each distance point in the base case show much larger variance than in ITS3. Some drivers approaching the base crossing were surprised by activated warnings with relatively high approaching speed and applied heavy braking. Although drivers at the ITS3 crossing did not encounter activated warnings, they received advanced warnings in the form of LED blocks. This caused drivers to slow down and provided adequate stopping time.

On the other hand, when drivers encounter a curve they have a tendency to slowdown to compensate for centrifugal force. Therefore there is relatively small difference between base and ITS3.

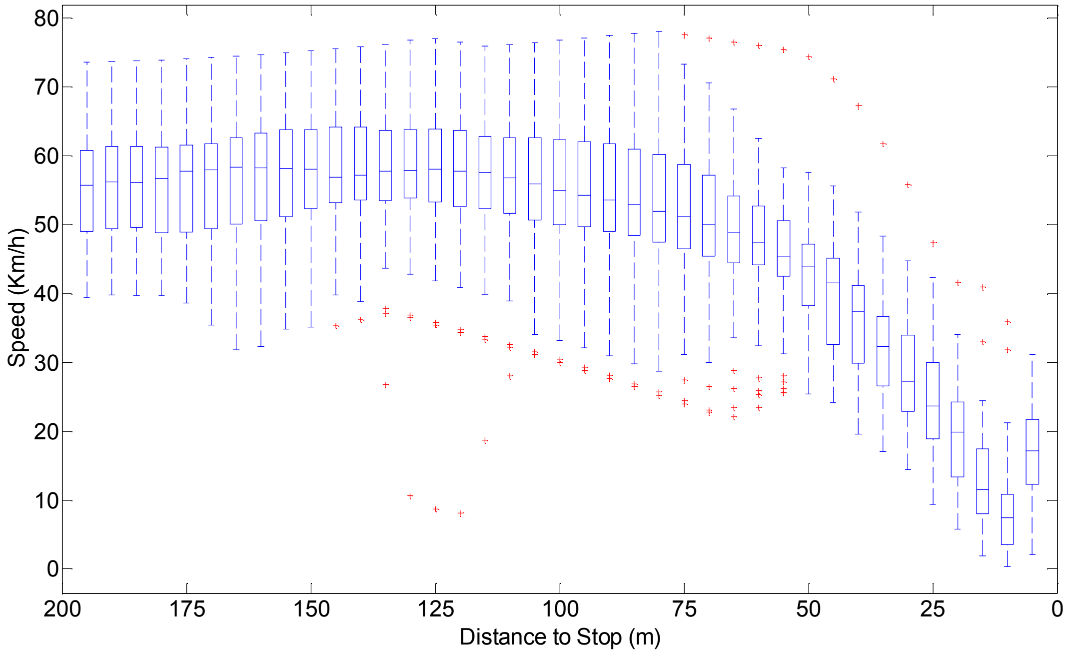


Figure 5 Speed profiles distribution at active crossing on straight with train-Base

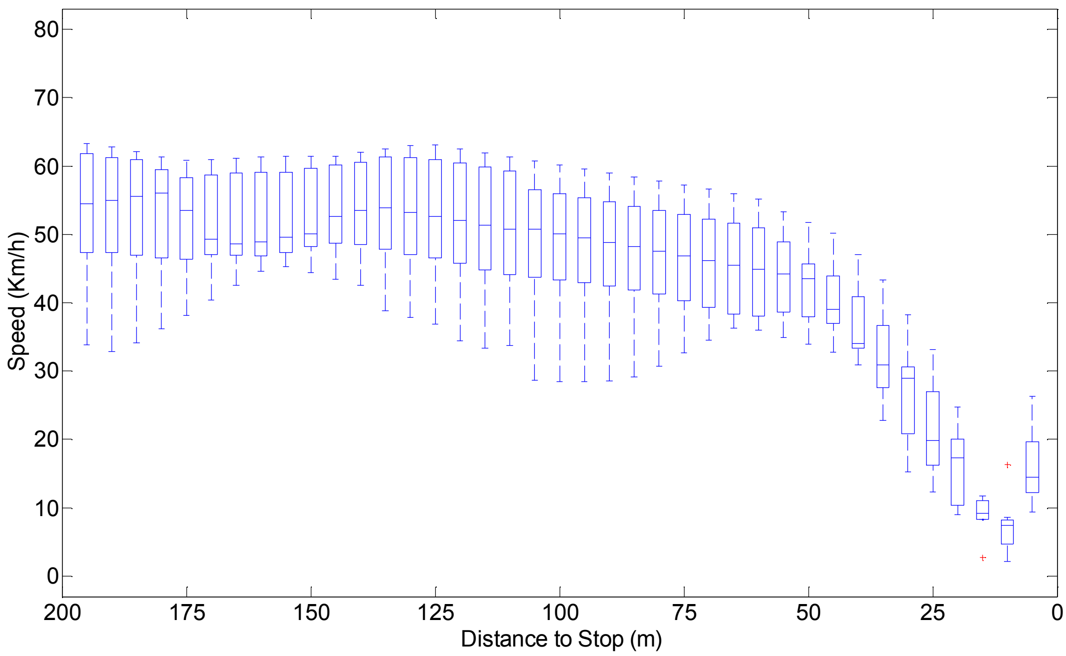


Figure 6 Speed profiles distribution at active crossing on straight with train-ITS3

Figure 7 shows that ITS treatments cause drivers to have lower speed profiles than the base case, after the warning begins. ITS3 helps drivers keep the lowest speed profile for all cases. Although ITS3 is not activated, drivers can see LED blocks in a row, causing drivers to decelerate.to ensure safety. Other ITS devices (ITS1 and ITS2) also provided earlier warnings than the base case. On the other hand, as shown in Figure 8, when no train is approaching at a straight course, drivers approaching the ITS interventions keep higher speed than the base case. Drivers trusted the reliability of ITS devices implicitly.

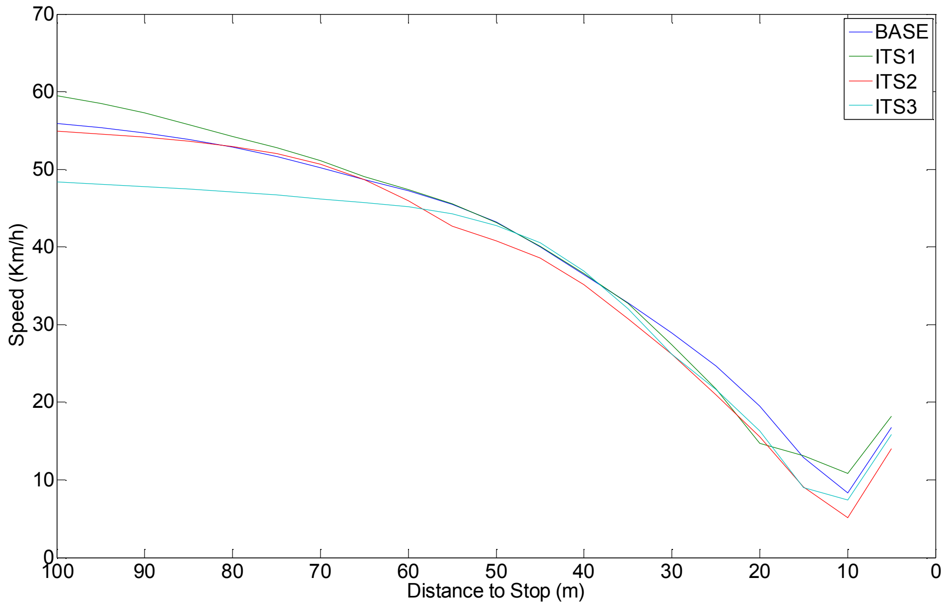


Figure 7 Mean speed profiles at active crossing on straight with train

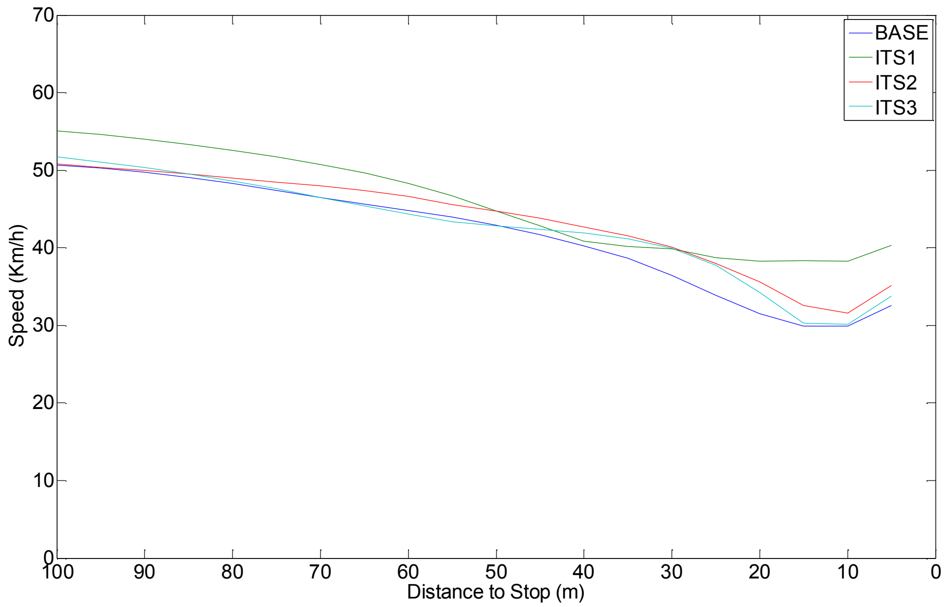


Figure 8 Mean speed profiles at active crossing on straight without train

4.3 Statistical analysis: comparing ITS interventions against base

The Wilcoxon test was performed to compare speed profiles. As there was no effect from 200 to 100 meters away from the stop line, the statistical test was conducted only 100 meters away from the stop line. Data was disaggregated into every 5 meters and averaged speeds at each point. The data was not normally distributed but rather right tailed. Therefore, the Wilcoxon test was selected to compare the paired data sets.

H0: The approaching speeds at base and ITS are the same.

Ha: The approaching speeds at base and ITS are different.

When a comparison result of two devices shows less than 0.05 (p value) H0 is rejected so that these two devices are significantly different statistically. P values in bold in the Table 3 and

Table 4 indicate that the approaching speed toward two devices (Base vs ITS) at an either passive or active crossing is significantly different. It is found that ITS devices are more effective when used at passive crossings.

There are more differences in straight courses than in curves at both passive and active crossings. This supports the idea that drivers might have unsafe driving behaviour on curves because their vision is not wide enough to observe whether any objects (a crossing, a train, or pedestrian) come up.

Table 3 Statistical analysis on passive crossing with train

Passive Crossing		Curb			Straight		
		ITS 1	ITS 2	ITS 3	ITS 1	ITS 2	ITS 3
Base	Curb	0.65	**0.00***	**0.00***	0.65	0.06	**0.00***
	Straight	**0.03***	**0.00***	**0.00***	**0.01***	0.48	**0.00***

Table 4 Statistical analysis on active crossing with train

Active Crossing		Curb			Straight		
		ITS 1	ITS 2	ITS 3	ITS 1	ITS 2	ITS 3
Base	Curb	**0.00***	0.55	**0.00***	0.15	0.16	0.97
	Straight	0.94	**0.01***	0.26	0.17	0.18	**0.00***

5. Limitations

This study does have some limitations. Although one subject generated 24 data (8 crossings × 3 runs) from the driving simulator, only one run tested ITS devices. Since this research is a preliminary experiment, more volunteers need to be used to support research results.

There were some comments from participants about the difference between the driving simulator and real world driving 'feel'. Some participants found it difficult to get used to manoeuvring in the simulator until nearly the end of the first drive. Drivers tended to stop further away from stop line in the simulator than in real life.

Nevertheless, this preliminary experiment produces an insight into the use of ITS devices. As a majority of railway collisions happen at passive crossings or active crossings without boom barriers, the use of ITS devices enables drivers to enjoy safer traveling. With more experiment and analysis, a deeper understanding on railway safety should be obtained.

6. Conclusions

In rural areas, it is not rare to encounter railway crossings equipped with single stop signs or flashing lights to protect drivers. This research intended to assess driver behaviour associated with the use of ITS devices. In this study, a number of tests were designed and tested; passive/active crossings, alone and with ITS devices on curved/straight roads.

This study provided some evidence that drivers respond to crossings with ITS devices earlier than without them. They help provide better compliance rates regardless of crossing type and road alignment when a train is approaching. ITS devices are more effective on curved roads since drivers can have time to prepare to stop although they cannot see directly where a train is.

Such treatments should improve driver awareness of the status of the crossings when the approach crossing is curved or on an incline.

However, when there was no train approaching many drivers violated the passive crossing on both curved and straight roads. Since drivers were educated about how the ITS devices worked they trusted and relied on these technologies. This driving behaviour might help traffic efficiency so that vehicles do not need to slow down and generate unnecessary delay. However, if the technologies malfunction it can create unforeseeable and possibly catastrophic consequences.

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