Summary

Level crossing collisions can be catastrophic leading to multiple deaths and significant financial losses. Some of the major factors contributing to level crossing accidents include lack of awareness of an approaching train, inappropriate driver behaviour, insufficient sight clearance for train visibility, and so on. As the technologies have advanced significantly, it is now possible to implement a more efficient and effective approach to prevent or even eliminate collisions at level crossing by providing sufficient information to motorists and train drivers before the intersection.

This paper presents a $5.5m Government and industry funded Cooperative Intelligent Transport Systems based solution that has been designed as a more efficient and effective approach to prevent and potentially eliminate accidents/collisions at road/rail crossing. Large scale field trials of the system at level crossing interfaces are producing promising outcomes and demonstrating that the developed solution can provide effective and actionable information to drivers approaching the rail/road interface. This is a major step towards the development of a comprehensive ITS based solution to improve safety at level crossings.

Introduction

According to the Australian Transport Safety Bureau (ATSB) between 2001 and 2009 over 630 road vehicle collisions occurred at level crossings in Australia with the state of Victoria alone accounting for 236 of these incidences [1]. In addition to the financial loss of level crossing accidents, they have also resulted in high level of tragic fatalities (over 70 deaths between 1997 and 2002 [2]).

Investigation by the ATSB into 12 level crossing accidents between April 2006 and December 2007 observed that nine of these incidences involved heavy road vehicles [3]. These incidences resulted in 19 deaths and an estimated financial loss of over $100 million, including a single incident near Karang, Victoria, where 11 people died.

The major factors which have accounted for collisions have included driver behaviour (and errors), poor communications, signalling difficulties, and environmental conditions such as visibility [4, 5, 6]. Existing approaches to improve safety include both passive and train activated warning signs and signalling systems. Although passive signs are economical to deploy, they can be less effective in addressing common causes of crossing incidences e.g. poor visibility, human errors due to fatigue or inappropriate driver behaviour [7, 8]. On the other hand, active warning systems such as boom gates can be expensive to deploy.

Furthermore, the absence of active warning systems or the presence of adverse weather or road conditions are not always the primary factors behind level crossing incidences. According to a study of 87 level crossing accidents conducted by ATSB [9], over 80% of the fatal accidents at level crossings occurred in excellent driving conditions that included daylight (excluding dawn and dusk), fine weather and straight and dry road. In addition to this, at least half of the level crossings involved in these collisions employed some form of active warning system such as boom gates, flashing lights or barriers. Driver error was the most common cause of level crossing collisions accounting for 46% of all incidents. Errors, however, are not mono-causal and range from attention lapses to false expectations, inappropriate decision making, driver mental overload and perceptual misjudgement [4, 5].

Over the past few years, the Federal and State Governments of Australia have made several recommendations [10, 11] to improve safety at rail-road crossings. Seven of these recommendations relate to the development and use of new Cooperative Intelligent Transport System (ITS) to improve safety at level crossings. The State Government of Victoria through the Public Transport Victoria and the Federal Government of Australia through the Cooperative Research Centre for Advanced Automotive Technology.
Cooperative Intelligent Transport Systems to Improve Safety at Level Crossings

Centre for Technology Infusion, La Trobe University & Public Transport Victoria

(AutoCRC) along with a number of key Universities and industry partners have cooperatively funded a new multi-million dollar project which aims at developing a co-operative Intelligent Transport System to improve safety at rail-road crossings. The specific aims within the scope of the project are to develop an Intelligent Transport System simulation platform for rail-road crossings based on 5.9GHz DSRC technology; to develop an ITS demonstrator system and to implement field trials with up to 100 vehicles at several level crossing interfaces. This paper presents the research, system architecture and the outcomes of this project.

INTELLIGENT TRANSPORT SYSTEMS (ITS)

Existing technologies, such as Global Positioning System (GPS), Satellite Communication, can be employed to establish communication between vehicles. Such Intelligent Transport Systems offer communication platform to facilitate sharing of information and knowledge within the transportation infrastructure to allow realisation of a range of safety and mobility applications. The development of the Dedicated Short Range Communication (DSRC) standard by the IEEE has paved the way to efficiently implement a wireless ad-hoc network, which can be used for vehicle-to-vehicle (V2V) and vehicles-to-infrastructure (V2I) communication to facilitate the development of ITS. ITS enables applications across three main categories, with the potential to offer significant social, economic and environmental benefits, namely:

• Safety: ITS safety applications use the communication mechanism within DSRC to create complete situation awareness for vehicles.
• Mobility: ITS mobility applications include travel and route planning, traffic and congestion management including public transport, transport network productivity and reliability enhancement etc.

Commercial: ITS can allow for a very wide range of commercial applications ranging from next generation electronic toll collection (ETC) and fleet management to a variety of data and infotainment applications.

Dedicated short range communication (DSRC)

In late 1999, the United States Federal Communications Commission (FCC) allocated a 75MHz spectrum for DSRC at 5.9GHz for use in Intelligent Transport System applications. The Australian Communication and Media Authority (ACMA) is also planning allocating a similar frequency spectrum in Australia [12]. The DSRC technology allows rapid and high speed communication between multiple vehicles and between vehicles and infrastructure to enable both safety and non-safety applications. This technology at 5.9 GHz offers 7 channels of 10 MHz each, allowing communication data rates of up to 27 Mbps, with communication capabilities at vehicle speeds up to 200 km/h. This next generation 5.9 GHz DSRC technology is based around a set of standards being developed by the IEEE.

THE PROJECT: INTELLIGENT TRANSPORT SYSTEMS TO IMPROVE SAFETY AT LEVEL CROSSING

The overall aim of the project was to research, develop, implement and trial (for potential rollout) a Dedicated Short Range Communication (DSRC) based Intelligent Transport System solution to improve safety at level crossings. The system aims to reduce and potentially eliminate rail-road crossing accidents by enabling dynamic vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications using DSRC technology. The specific aims within the scope of the project are:

• Phase 1: To develop an Intelligent Transport System (ITS) simulation platform for rail-road crossings based on 5.9GHz DSRC technology
• Phase 2: To develop an ITS demonstrator and Proof-of-Concept system
• Phase 3: To carry-out field trials at level crossing interfaces

Figure 1 illustrates the system architecture of the proposed DSRC based Intelligent Transport System deployed at a level crossing. The system is composed of DSRC enabled roadside units (RSUs) and on-board units (OBUs). The RSUs are placed at locations such as rail-road crossing active signs while the OBUs are installed in road vehicles and trains.

A DSRC based ITS at level crossing will enable communication between infrastructure nodes and vehicles in the vicinity of the crossing including trains and road vehicles. This communication will enable sharing abundant data between vehicles including basic information such as vehicle size and type, position and motion and other control information such as brake status, throttle, steering angle etc. Depending on various parameters and conditions, the information can be shared directly using V2V communication or indirectly using V2I communication as presented in Figure 2. The information will be used by a specialised level crossing safety application to generating warning messages such as advice of an approaching train, advance indication of a potentially faulty crossing, expected delay at the level crossing, suggestion of alternate routes etc. The Human-Machine-Interface (HMI) used to communicate safety messages to drivers.
was developed to not only address the immediate safety requirements but also to promote overall long term behavioural change of drivers towards safety consciousness.

Figure 1: Architecture of DSRC-based ITS for Level Crossings

Figure 2: DSRC Communication Scenarios
Simulation platform

Existing simulation platforms/tools such as CarSim/TruckSim, Network Simulator 2/3 (NS2/NS3), Coloured Petrinet (CPN), Simple Simulation of Driver (SSDrive), Automated Highway Simulations (AHS) are generally domain specific. Most high-end simulation platforms are commercial, closed-source projects and co-simulation can be extremely computation-intensive in nature. The overall result is a limited capacity for simulation systems to perform simulations on a larger scale in a respectable time that will allow real empirical evaluation of a system.

To address the limitations of existing solutions, this project involved the development of a DSRC based ITS simulation platform which can accurately simulate the mobility, DSRC communication and complete interaction of trains and road vehicles at a level crossing. Figure 3 illustrates the architecture and the elements of the simulation platform. The platform has been developed to allow simulation of all domains in a unified simulation environment that is specialised for level crossings.

The features of the simulation platform include:

- Distributed High Performance Computing (HPC) cluster based simulation environment supporting execution of simulations involving a large number of nodes/models and also a large number of potential scenarios
- Scalable models of DSRC communication, GPS, Intelligent Collision Avoidance Applications, Vehicle models (articulated trains, buses, trucks, cars), Mapping system models, and Human behaviour models (driving behaviour and HMI) enabling simulations of a broad cross section of scenarios for V2V/V2I networks
- Flexible parameter configurability and efficient simulation trace/debugging/event filtering mechanisms for all models to allow Design of Experiment (DoE) and heuristic search
- A complete simulation set-up/visualisation engine with graphical user interfaces that includes real-world map loading, drag and drop of element placements, optimal traffic routing and parameterisation of various elements. It also supports automated simulation execution on remote clusters and simulation data visualisation with motion control

The simulation platform allows detailed modelling and forecasting of the typical interactions between rail and road traffic. A simulator normed with complex empirically collected field trial data can be used to further the design of intelligent collision avoidance algorithms, and visually and intuitively evaluate system boundary conditions for safety factors such as the predicted motion paths of vehicles, different configurations of collision warning thresholds, and human behaviour variations on attributes such as reaction time, driving style or attentiveness. With its high level of customisability, this platform has the potential to direct the design and implementation of practical DSRC road-safety infrastructures and mobile devices.
Demonstrator system

A demonstrator system was developed for lab-based tests using Cohda Wireless’s 5.9GHz DSRC radio platform. The main objective of this work was to establish a proof of concept through the development of a technology demonstrator based on 5.9 GHz DSRC technology. The most significant aspects of this work include:

- Development of optimised embedded software for DSRC-based safety applications based on intelligent new algorithms for proactive collision avoidance, human factor research outcomes, and work leading towards congestion and emission reduction.
- Identification, development, and implementation of core technologies for HMI, including both functionality and display characteristics of HMIs and drivers’ behaviour issues. The resultant HMI interface was designed to be scalable.
- Lab-based tests carried out to validate the overall functionality and evaluate critical performance parameters of the DSRC-based ITS solution that will be further improved during and after the field trials at level crossings.

Human machine interface (HMI)

While there are already numerous in-vehicle HMI implementation in existing vehicles that address forward collision or lane departure, there is currently no system dedicated to provide timely and effective train warnings at rail level crossings. In contrast to other safety alerts, train warnings can be transmitted a considerable amount of time prior to the level crossing interaction, thereby eliminating the potentially critical information overload of drivers in a high risk situation. On the other hand, warnings must not be delivered too early to avert nuisance perception and attentional lapse.

In this project, the HMI was developed through a combination of focus groups, and experimental tests, and field trial feedback. In line with ISO guidelines for the presentation of in-vehicle information, the final HMI incorporated a Head-Up Display (HUD) in the form of a touch screen LCD device appropriately mounted on the dashboard. Audio-visual warning messages, as shown in Figure 4, dynamically intensify on multiple dimensions (volume, pitch, semantic content, contrast, static versus dynamic image animation) as driver risk increases.

Figure 4: (a) Warning sequence on a direct, perpendicular approach, (b) adaptive warning when approach to level crossing is not direct
Field trials

Phase 3 of the project involved conducting real-world field trials of the system with a large number of vehicles at level crossings in urban and rural locations for verification, data collection, and overall system optimisation. Three trial sites were selected and the Scientific License to carry out field trials was obtained from ACMA. The field trial objectives were to:

- verify the implementation of the DSRC-based safety application;
- verify the effectiveness of the Human Machine Interface (HMI) across a spectrum of driving conditions;
- collect real world data for analysis and further enhancement of the algorithms in the Simulation Platform and Demonstrator System;
- assess and improve the Simulation Platform’s scalability, reliability, and performance.

The field trials used Cohda Wireless’s 5.9GHz DSRC radios to test, specifically in the context of rail-road crossings:

- radio communication performance under adverse conditions including vehicular congestion, ‘high’ speed vehicular interactions, and built environment operation;
- key system performance factors including data rate, application response, multipath fading, Doppler effect, on-time reception of safety critical messages, and GPS positioning accuracy;
- driver reaction (risk reduction) factors such as message effectiveness, usability of the HMI, and effect of a passenger on the driver.

The schedule of testing conditions at each of the trial sites is summarised in Table 1. For these orchestrated trials, drivers received explicit instructions about their driving routes and their approach speeds. These logistical aspects were necessary to ensure that train and drivers would arrive at the level crossing at about the same point in time and that the specific scenarios defined a priori could be enacted.

In addition to the orchestrated trials, a six week longitudinal trial was conducted at the two urban trial sites. Ten local drivers were recruited to drive across the level crossing as they normally would and 16 radios were fitted to eight live trains that passed through the DSRC controlled level crossing. The aim of this project phase was to gather data on alert adaptation over time, system acceptance and, if applicable, changes to driver behaviour as a result of exposure to warnings.

<table>
<thead>
<tr>
<th>Table 1: Field trial scenarios at Urban and Rural trial sites.</th>
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<tr>
<th>Orchestrate Scenarios (with different approach speeds where applicable)</th>
<th>Rural (7 vehicles)</th>
<th>Urban 1 (70 vehicles)</th>
<th>Urban 2 (30 vehicles)</th>
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<tbody>
<tr>
<td>Mass vehicles in vicinity of the crossing</td>
<td>X (40-100 km/h)</td>
<td>X (30-60 km/h)</td>
<td>X (30-60 km/h)</td>
</tr>
<tr>
<td>Road vehicles approach perpendicular to crossing</td>
<td></td>
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<td></td>
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<tr>
<td>Road vehicles approach parallel to crossing</td>
<td>X (40-100 km/h)</td>
<td>X (30-50 km/h)</td>
<td>X (30-50 km/h)</td>
</tr>
<tr>
<td>Road vehicles turn away from crossing (from direct or indirect approach)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road vehicles turn in towards crossing from side street</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
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Special Scenarios

- Hard deceleration on high urgency alert
- Obtuse angle approach (interaction) involving high speeds (100km/h) for vehicle and trains

London, 8 – 10 October 2012
OUTCOMES

The final stage of the trials was being completed at the time of writing this paper, and preliminary results from the completed field trials are presented in this section. The key results available are related to the driver’s interaction with the system during first part of the orchestrated field trials. The evaluation of the driver experience focused on drivers’ perceived ease of use of the system, perception and assessment of the individual alerts with respect to both nuisance and safety, and, most importantly, a global assessment of system effectiveness.

Across all field trial conditions participants reported a high level of effectiveness for the alerts. As displayed in Figure 5, ratings were highest for the most noticeable and intrusive alert, and lowest for the low level advisory notification. This result was in keeping with the objective of design, that alerts should be non-intrusive in non-threatening situations.

A second important factor for the overall assessment of effectiveness is the appropriateness of alert timing. Early alerts are likely to lead to driver frustration, while late alerts present a significant safety hazard. The alert timings in this project designed iteratively around the core NHSTA collision avoidance algorithm to determine the latest possible point at which an urgent warning needs to be presented. Figure 6 illustrates the driver’s response for the urban field trial.

![Figure 5: Average effectiveness rating (with standard deviations) for each of the three alert levels (n = 85)](image)

![Figure 6: Driver assessment of alert timings (n = 70)](image)
A third important aspect was drivers’ perceived level of distraction and startle. Both of these are safety-critical in emergency situation as they lengthen reaction time and impair appropriate decision making. Aggregated across all alerts, participant drivers reported low levels of both distraction and startle as presented in Figure 7. Distraction was more common for low level alerts than for high level alerts, possibly because the change in display caused participants to pay attention to the screen and anticipate higher levels of alert. The opposite was true of startle, which participants reported more frequently for higher level of alerts than for low level alerts. Startle only occurred when participants received warnings unexpectedly in situations that were ambiguous, for example when participant turned into a side street away from the crossing just prior to reaching the crossing and reduced speed very late.

Overall, the data collected in this project provide some understanding of the behavioural effects brought about by the in-vehicle alerts. Importantly, the data suggest that participants perceive the system to be effective, while at the same time not to be overly intrusive or otherwise adverse. This is a crucial aspect in determining the likelihood of uptake and acceptance by drivers. The second aspect, whether unintended side effects such as startle or attentional distraction could result from in-vehicle train warnings is more difficult to answer unequivocally on the basis of the available data. Primarily this is due to the semi-artificial nature of the orchestrated trials, during which participant drivers were fully aware that within the next 1-2 minutes they would be exposed to a train warning. The longitudinal field trial, which concluded at the time of writing this paper, on the other hand, did provide data from unanticipated encounters between road- and rail vehicles, yet the nature of the trial prevented a similar rigor of data collection (e.g., no in-vehicle video recording) that was implemented during the orchestrated trial. Future projects will address this aspect specifically by adding to the existing data and through tests of additional scenarios both under laboratory and field conditions.

CONCLUSION

Level crossing collisions can be catastrophic in nature and lead to tragic deaths and significant financial losses. Study and analyses carried out by the Australian Transport and Safety Bureau have indicated that driver error is one of the most significant factors that lead to collisions at level crossings. DSRC technology has the potential to offer a cost effective means of deploying an Intelligent Transport Systems offering social, economic and environmental benefits.

This paper has presented the overview of the research, system architecture and the preliminary outcomes of a $5.5 million Intelligent Transport Systems to Improve Safety at Level Crossing project. This project has resulted in development of a complete proof-of-concept safety solution for improving safety at level crossings. The outcomes indicate that the DSRC technology has performed under adverse conditions including vehicular congestion and preliminary results from large scale field trials of the safety solution indicate that overall, drivers perceive the system to be effective and largely resilient to adverse effects. Broadly, the solution will not only result in immediate safety outcomes in terms of collision avoidance, it may also help in long term behaviour change of drivers and result in an overall improvement in safety consciousness on Australian roads.
REFERENCES

[12] Australian Communications and Media Authority (ACMA), Planning for intelligent transport systems - proposals for the introduction of intelligent transport systems into the 5.9 GHz band in Australia, 2009.