IN-VEHICLE RAILWAY LEVEL CROSSING WARNING SYSTEMS: CAN INTELLIGENT TRANSPORT SYSTEMS DELIVER?

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SUMMARY

Intelligent Transport System (ITS) technology is seen as a cost-effective way to increase the conspicuity of approaching trains and the effectiveness of train warnings at level crossings by providing an in-vehicle warning of an approaching train. The technology is often seen as a potential low-cost alternative to upgrading passive level crossings with traditional active warning systems (flashing lights and boom barriers). ITS platforms provide sensor, localization and dedicated short-range communication (DSRC) technologies to support cooperative applications such as collision avoidance for road vehicles.

In recent years, in-vehicle warning systems based on ITS technology have been trialed at numerous locations around Australia, at level crossing sites with active and passive controls. While significant research has been conducted on the benefits of the technology in nominal operating modes, little research has focused on the effects of the failure modes, the human factors implications of unreliable warnings and the technology adoption process from the railway industry’s perspective. Many ITS technology suppliers originate from the road industry and often have limited awareness of the safety assurance requirements, operational requirements and legal obligations of railway operators. This paper aims to raise awareness of these issues and start a discussion on how such technology could be adopted.

This paper will describe several ITS implementation scenarios and discuss failure modes, human factors considerations and the impact these scenarios are likely to have in terms of safety, railway safety assurance requirements and the practicability of meeting these requirements. The paper will identify the key obstacles impeding the adoption of ITS systems for the different implementation scenarios and a possible path forward towards the adoption of ITS technology.

1. INTRODUCTION

Crashes between road vehicles and trains at railway level crossings continue to be a significant concern for railways, with more than 23,500 level crossings across Australia [1]. Approximately a third of rail-related fatalities occurred at the road-rail interface as a result of collisions between road vehicles and trains in the ten-year period from 2000 to 2009 [2]. This was based on a comparison of total rail related fatalities published by the Australian Transport Safety Bureau for the ten-year period from 2001 to 2010 [3] and level crossing fatalities from collisions between road vehicles and trains published by the Independent Transport Safety Regulator, NSW for the ten-year period from 2000 to 2009 [2], (occurrence data from Australian Transport Safety Bureau was not available prior to 2001). Approximately 45% of these fatalities occurred at level crossings with passive controls, the remainder at level crossings with active controls comprised of either flashing lights or both flashing lights and boom barriers [2]. Lack of awareness of an approaching train was identified as the key issue arising from the 1989 Victorian railway level crossing inquests of seven fatal level crossing accidents [4]. Further to these findings, in 2000 the coroner issued a viewpoint on accidents at railway crossings, citing that there had been little progress on “inexpensive and effective means of warning motorists of an approaching train”.

In 2008 the parliament of Victoria published the findings and recommendations from a parliamentary inquiry into improving the safety at level crossings [5]. The report investigates new and developing technologies for improving safety at level crossings, with a focus on Intelligent Transport Systems (ITS) and other approaches such as low-cost level crossing warning devices. The report recommended that the development,
trial and adoption of ITS infrastructure be pursued (recommendations 31-35 [5]). The recent findings from the inquest into 26 level crossing deaths including those at the Kerang level crossing incident [6] (published in 2013), have reiterated the need to "investigate and implement new level crossing infrastructure which is designed to alert road vehicle drivers to an approaching train whom are unresponsive to the current suite of level crossing warning signs".

While there has been research and trials of ITS-based in-vehicle warning systems in Victoria and Queensland, the majority of the research has focused on benefits of the technology rather than addressing reliability, safety and overreliance issues of the technology.

This paper brings together the views of a software engineer, railway signalling engineer, human factors specialist and level crossings manager to provide a balanced discussion around the issues and obstacles impeding the adoption of ITS-based warning systems, and two possible ITS development strategies with a medium and longer term perspective.

2. IMPROVING LEVEL CROSSING SAFETY WITH ITS

In-vehicle level crossing warning systems based on ITS technology have the potential to enhance existing fixed infrastructure warning systems and improve road user response. The technology aims to achieve this by increasing the conspicuity of an approaching train through targeted advice provided within the vehicle.

Level crossings controls have remained virtually unchanged since the 1920s. The effectiveness of the current suit of active warning devices has been widely criticized given the number of incidents in which active warnings did not invoke a driver response (e.g. level crossing collision at Kerang in 2007 [7]). Improving road user awareness of approaching trains is a key issue for level crossing safety.

ITS-based warning systems represent a fundamentally different method of providing level crossing information to road users. The technology additionally provides the opportunity to deliver an enhanced level of information to road users – e.g. inform road users of multiple trains and communicate effectively the state of a level crossing.

ITS technology can support several communication paradigms including vehicle to vehicle (V2V), train to vehicle and infrastructure to vehicle (I2V) communications. The technology could potentially be used to make road users aware of an approaching train at level crossings either as an overlay to existing active controls (flashing lights / boom barriers), as a stand-alone system in addition to active controls, or as a stand-alone system in addition to passive controls (stop or give-way signs).

3. CONSIDERATIONS FOR THE ADOPTION OF AN ITS-BASED LEVEL CROSSING WARNING SYSTEM

3.1. Human Factors Considerations of In-vehicle Warnings

One of the most important aspects of any warning system is its effectiveness from a human factors perspective. This section discusses a number of human factors considerations including design of the road vehicle human machine interface (HMI), design of warnings from a functional perspective, and the design of the HMI for the configuration and management of on-board train systems used in train to vehicle communication paradigms. The ability of ITS-based warning systems to either enhance or integrate with the vehicle’s internal information displays is a fundamental advantage, which overcomes many disadvantages of traditional, external warning methods.

3.1.1. Road vehicle human machine interface

The design of the HMI is a critical aspect of any internal level crossing information and warning system. Driving requires visual attention and provision of further in-vehicle information using either traditional visual methods through either Head-Down (HDD) or Head-up Displays (HUD) may not be the best solution and may actually decrease attention to the primary external field of view. This is particularly a concern at level crossings with passive controls, where the road user has the responsibility to scan the external field of view for an approaching train.

Enhanced visual displays to highlight salient features of the external view (for example, pedestrians, lane markings and signage under degraded lighting conditions) have been trialled and similar methods could be applied to a level crossing ITS display. Auditory alerts are rudimentary in current vehicles and can be improved by iconic signal design, which provides both type and directionality of information. However, auditory inputs are subject to interference from other sources such as entertainment systems and mobile devices.

Inattentional blindness, inattentional deafness and individual visual and hearing impairment are factors that need to be considered; there is no guarantee that either visual or auditory warnings will be perceived and subsequently acted upon [8, 9]. Tactile / haptic methods have proven to be effective in defence applications [10] and their adaption into vehicles promise another layer of information presentation either supplementing
other modalities or acting as primary warning systems (although use of an ITS-based level crossing warning system as a primary warning would currently not be contemplated due to considerations discussed later in this section). Further research into this aspect is required as congruent information provided across all sensory modalities not only provides redundancy and flexibility but will also enable the optimal method for imparting warning information dependant on particular circumstances.

Warnings signals ideally need to be intuitive and affective, or induce the appropriate behavioural reaction, in order to be effective. Although some standards exist with regard to symbology in road vehicles, these may vary across manufacturers with cursory usability testing. Similarly, auditory alerts are typically abstract and require deciphering by the driver to deduce meaning. Iconic signal selection provides inherent meaning and affect. Directionality can also be incorporated into well-designed multi-sensory systems.

Level crossing ITS warning frequency would vary from rarely to frequently depending on circumstance. It is important that instant recognition be a critical factor of system design.

3.1.2. In-vehicle warning from a functional perspective

One of the key issues around the adoption of in-vehicle warning systems is its use at level crossings with passive controls. There is concern that providing warning of an approaching train at this type of crossing would result in the system becoming a de-facto primary control as a result of road users becoming over-reliant on the technology.

A simulation study conducted by the Cooperative Research Centre for Rail Innovation [11] found that a significant proportion of participants modified their driving behaviour when approaching level crossings with passive controls, where the in-vehicle warning technology was present. The modification of behaviour was consistent with increased approach speeds and a reduction of active scanning found at level crossings with active controls. Furthermore, a number of the participants no longer complied with the stop signs at level crossings with passive controls when the in-vehicle warning was present. The study was performed in an immersive simulation environment using a vehicle on a motion platform.

Even though the observations were responses of participants to a simulation, it is not unreasonable to assume that the observed behaviour would transfer to the real-world road environment. Over-reliance on the technology must therefore be considered in terms of the functions the technology provides and the reliability of these functions, especially in situations where the existing level crossing controls do not provide a train approach warning.

Ideally, any system would be designed to encourage a user to visually scan the level crossing – in effect a multi stage process which would firstly alert to the presence of a level crossing, either provide information as to a train approach and its direction or a fault alert – the desired result would be to orient visual attention to the potential threat, whether it be an actual train as detected by the system, or the physical level crossing itself and potential for approaching trains if and when the system is not operating.

In terms of the warning functions and information sets provided to road users, integration of current systems with ITS would need careful consideration so that inconsistencies or competition between the systems does not occur. For example, inconsistencies in minimum warning times between active level crossing warnings and the in-vehicle warnings could lead to reduced compliance with fixed infrastructure warnings and over-reliance on the in-vehicle technology, which is unlikely to be as reliable as the existing infrastructure.

However, infrastructure level crossing systems are often constrained by a number of factors that may contribute to a less than optimal warning. For example, level crossings controlled by track circuits will provide longer warnings for slow trains and in the case of a second train engaging the level crossing, the warning will remain engaged for an extended period. Further research is required to determine how best to provide warning consistency and optimal warning times, potentially through a hierarchy of warnings. Ideally, the infrastructure and in-vehicle system would be configured to provide a seamless integration or transition from legacy to ITS systems. Establishing optimal warning times for in-vehicle systems would require consideration of human memory, attention capabilities and limitations. Warnings should be presented with adequate time to take action according to the circumstance, but not be excessive. Further research is required to quantify this.

Lastly, the implications of a multi-application environment would need to be considered. The level crossing warning application would potentially be one of several applications on a standardized computing and communications platform. The road industry is currently developing and standardizing such platforms based on Dedicated Short Range Communications (DSRC).

The acceptance that a level crossing warning application would be part of an integrated suite of applications (such as collision warning, emergency electronic brake light, dangerous conditions...
warning, etc.) would enable a holistic design of the overall system. Multimodal information display, standard and congruent warning methods across platforms, and a hierarchy of alerts would need to be a central theme requiring some form of mandated standard. Any alerts would ideally be standard across vehicles, instantly recognised and responsive to particular circumstances so that they have similar effectiveness over a range of conditions. A similar requirement as per the national rail safety legislation that human factors be incorporated into any initiatives and be formulated by professional and experienced HF practitioners may be necessary [12].

3.1.3. Rail human machine interface for train-borne systems

An ITS-based level crossing warning system that utilizes train to vehicle communications would need to carefully consider the design of the HMI used to configure and monitor the state of train-borne on-board units (OBUs).

In some “train to vehicle” implementations, the length of the rail vehicle may need to be configured in the OBU so that the warning function can determine when the rail vehicle has passed the level crossing clearance point. While length for passenger trains could potentially be set for the largest consist or location determination units fitted to the front and rear of each rail car set, freight trains require special consideration as they would have other factors e.g. lack of side-lights and variety of consist, which differ from typical passenger trains.

Changing consists and last minute operational changes could result in insufficient or excessive warnings if the on-board configuration does not reflect the train configuration. The design of the HMI would also need to consider how human interaction with the system for configuration and monitoring would affect the workload of the train crew.

3.2. Technical Considerations

The previous subsections have discussed the design of HMI and warning functions from a human factors perspective. It is particularly apparent from these discussions that integrity and reliability of the system are critical aspects of system design, especially where road users are prone to over-reliance on the technology. This section will discuss technical considerations of various approaches to implementing ITS-based warning systems and their potential effect on safety.

Where ITS-based warning systems are based on a train to vehicle communications paradigm, the following issues would need to be considered:

- To ensure that a warning is provided for all approaching trains, 100% of rail vehicles including track maintenance and hi-rail vehicles would need to be fitted with an on-board unit (OBU).
- In the case a train-borne OBU fails, the effect of the failure is that no warning would be provided to road users for all level crossings with passive controls traversed by the train while the OBU remained in a failed state. If in-vehicle warning systems or road vehicles are unable to detect the failure of a train-borne OBU, then this failure results in a dangerous state for all passive level crossings traversed by the train. Despite the presence of passive controls and the obligation of road users to look for trains, over-reliance on the in-vehicle technology could potentially lead to a collision.
- To mitigate the risk resulting from an OBU failure, trains may have to stop or approach level crossings at a significantly reduced speed. This could severely impact operations and potentially result in large losses to the railway operator in terms of delays, etc. Reliability requirements of the OBU (and associated cost) may need to be balanced against the potential financial impact of stopping or slowing down trains.
- Railways generally have procedures for operating in degraded modes due to failure conditions. An added complexity of this type of failure is that it manifests itself to road users. Persistence of the failure is also an issue, as a train may not be able to stop as a result of the failure. While the train continues operation with a failed OBU, road users are exposed to an increased level of risk at level crossings. Perhaps an extra level of conspicuity of trains in this instance, or a fail-safe function that reacts when a failure mode is detected could be a solution.
- Configuration management for train-borne OBUs needs to be considered, especially where track databases or maps (i.e. with level crossing locations) are used by train-borne location determination systems. Addition, removal or modification of level crossings would need to be reflected in the respective train-borne systems.
- Localization technologies such as GPS are a key component to the “train to vehicle” paradigm. As the location function is used to determine when the train is approaching a level crossing in order to provide a warning, it is inherently safety-related. As such, errors or failures in the location determination function can result in excessive, insufficient or no warning to road users. There is precedence for
high-integrity location determination for automatic train protection and control functions. For example, ERTMS level 2 and some ATP systems calculate position on the track using wheel odometry calibrated by balises and have Doppler radar to compensate for wheel slip and slide. ATMS on the other hand, calculates position using an on-board track database containing absolute reference points and a Kalman filter combining GPS with wheel odometry and inertial sensors [13]. Train-borne OBUs could potentially interface with existing vital location determination systems, especially for railways that are planning ATP or ERTMS deployments.

The following technical issues related to the in-vehicle on-board units in road vehicles would need to be considered:

- The road user should be made aware of the operating state of the in-vehicle warning system. Failure of the system to provide the warning function (whether it be due to failures of hardware, software or communications) should be evident to the road user. If the system is unreliable, road users will tend to disregard it or lose confidence in its accuracy. It is highly important to ensure that the system is tried and tested before release to the general public.

- One of the key features of in-vehicle warning systems is the ability to provide context-aware warnings (e.g. a different warning when a road vehicle is travelling parallel to a railway compared with a direct approach to a level crossing). Future systems may include some form of input as to the intent of the operator. For example, if the planned route does not cross the railway, there would be no need to provide any warning information at all, thus eliminating spurious and unnecessary warnings (except where the vehicle changes course with respect to the planned route). The ability to toggle the system according to intent, or another method of communicating this to the system is desirable. Integration with GPS and route planning software could be a means to achieving this aim.

- If the in-vehicle warning system has been designed to provide context-aware warnings, dependent functions such as mapping, routing and location determination effectively become safety-related functions. Errors in the mapping, routing or location determination functions could cause incorrect warnings or no warning at all to be provided to road users. Ensuring accuracy and maintenance of map data as well as integrity of the location determination function are important issues that would need to be considered.

3.3. Adoption Considerations

In addition to human factors and technical issues, adoption of the technology presents some unique challenges.

From the rail perspective, a key issue with the progressive implementation of ITS infrastructure is that not all crossings would provision an in-vehicle warning to road users. Where in-vehicle warnings are provided to road users in addition to existing active controls, it may be possible to make an argument for a progressive implementation. A public education program would appear a necessity with the introduction of the road vehicle component into operation, where mechanisms to advise road users of updated or modified functionality would need to be considered.

For ITS systems based on a train to vehicle paradigm, the implementation strategy would be complicated by the possible use of the technology to provide a train approach warning to road users at level crossings with passive controls. The railway operator would need to ensure 100% of the fleet (including hi-rail and maintenance vehicles) is equipped with the train-borne OBUs before the warning system is made operational. It is unlikely a transitional approach involving a staged implementation on a corridor basis would be practicable, even if workable from a rail perspective.

Adoption of ITS-based level crossing warning systems will impose ongoing resourcing and cost considerations, particularly on the rail and road authorities. For I2V scenarios, the installation, monitoring and maintenance of road-side ITS infrastructure would be required. Depending agreements between road and rail authorities, road-side ITS infrastructure could be maintained by road authorities. While the rail authorities may have the resources and skill sets to install, maintain and monitor ITS equipment (train-borne or track-side), many councils may not. For I2V scenarios involving the installation of road-side ITS infrastructure that interfaces with railway systems, a coordinated approach is required.

From the road perspective, adoption of on-board units in road vehicles is one of the key issues. In order to ascertain the expected magnitude of risk reduction provided by ITS-based in-vehicle warnings, the expected uptake of the technology needs to be understood. While there are many projections of future cars providing multi-application platforms and the availability of after-market units, without a government mandate or incentives, uptake by road users could be one of the biggest obstacles this technology faces.

Government programs such as the Intelligent Access Program (IAP) could provide an ideal platform to target higher-risk vehicles. IAP is a
tracking system for compliance, where operators of high-risk vehicles (e.g., heavy vehicles) agree to installation of the remote monitoring in return for less restrictive road access. High mass permit vehicles may be able to have the installation of the units mandated as part of the licencing regime.

Whilst after-market units may be the easiest method of disseminating new technology into the older vehicle fleet, the urge to make DSRC technology widely available must be tempered by how these units will be integrated into the vehicle. There is evidence for example, that poor placement of GPS navigation units can impact on visibility, contribute to driver distraction and significantly degrade overall safety. A framework for determining how new technology is integrated into vehicles without compromising existing systems is highly desirable. The easiest and cheapest method may not always be the best nor safest.

3.4. Obstacles to Adoption of ITS

Liability for failure of an in-vehicle warning system resulting in a collision is one of the major concerns of railway operators in adopting ITS-based technology, particularly where train-borne on-board units (OBUs) are installed. Consider a level crossing with passive controls. There is a degree of shared risk ownership. The railway is responsible for ensuring that the level crossing has sufficient sighting, for maintenance activities stipulated in the safety interface agreement (SIA), etc.; the road authority is responsible for approaches to the level crossing and maintenance activities stipulated in the SIA; and the road user is responsible for obeying road rules and checking for trains before traversing the crossing.

Where technology is implemented to reduce risk at a level crossing, the railway is likely to be responsible for the additional liability related to the dangerous failure of that technology (e.g. when flashing lights fail to operate when train is approaching). This additional liability however, is offset by the liability of having high-risk level crossings with passive controls (e.g. with inadequate sighting). In the case of ITS-based in-vehicle warning systems, the clear delineation of responsibility is blurred by the distributed nature of the technology – i.e. the technology has train-borne, road-side and in-vehicle components. These issues of legal liability also occur in the road environment for other I2V applications and are being considered as part of the general development of the technology; however, the particular requirements of the rail environment must also be satisfied.

From the railway’s perspective, a number of questions arise: Where does responsibility for correct functioning of the system lie? Is it restricted to ensuring that train-borne OBUs are operational or does it extend to provision of a warning to the road user? Who is responsible for ensuring the integrity of the in-vehicle OBUs (i.e. regular maintenance and testing)? From the railway’s perspective, how could a safety case be developed around a component in a person’s vehicle?

In the event of a failure resulting in no warning being provided to the road user of an approaching train, how would the source of failure be determined? Would the railway be liable if an in-vehicle unit did not receive the signal from an approaching train? There are instances where the train-borne OBU would be operating correctly and transmit a signal, but due issues in the propagation environment (e.g. interference, etc.), the signal may not be received by the in-vehicle OBU.

Further research is needed to identify in-vehicle technologies and communication paradigms that can be adopted within the current legal and regulatory landscape, and whether a case for legislative change indemnifying rail operators of liability in certain circumstances could (or should) be made.

In addition to responsibility for technical failures, reluctance to adopt these new technologies is also influenced by the lack of substantial evidence supporting the effectiveness of these systems. In order to determine whether implementation of such systems is reasonably practicable, it is necessary to quantify the magnitude of risk reduction afforded by the adoption of in-vehicle warning systems. Larger trials and further research to determine uptake of in-vehicle systems are required to facilitate this. A holistic human factors analysis of all effects from ITS systems can assist in assessing and quantifying these risks.

4. PROPOSED ITS DEVELOPMENT STRATEGIES

This section describes a possible path forward for the development and adoption of ITS-based in-vehicle level crossing warning systems. Based on the human factors, technical and commercial considerations discussed in the previous section, two strategies are described:

- A short/medium term development strategy based on an infrastructure to vehicle (I2V) communications paradigm with the view to addressing recommendations from the Kerang coronial inquest [6] relating to the use of in-vehicle warning technologies; and
- A longer-term research and development strategy investigating vehicle-to-vehicle (V2V) communication paradigms (where V2V includes train-to-vehicle communications) in
addition to the I2V paradigm developed in the earlier strategy.

The philosophy behind the first strategy is to find a pragmatic way forward for in-vehicle level crossing warning systems within the current regulatory and legislative frameworks, allowing for a large test-bed deployment to gather additional data under in-service operating conditions.

The cornerstone of this strategy is a clear delineation of responsibility between road and rail authorities, where interface agreements, as required under the national rail safety legislation (subdivision 2 – interface agreements) [12], would provide the framework for demarcation of roles and responsibilities in relation to the implementation and maintenance of in-vehicle warning system infrastructure.

The current suite of research on low-cost level crossing warning devices being conducted by the CRC for Rail Innovation would complement this strategy. Low-cost level crossing warning devices (LCLCWDs), as with conventional level crossing warning devices, provide a vital train approach indication that can be interfaced to in-vehicle warning system infrastructure.

The low-cost level crossing research programme is not only conducting a national trial of LCLCWDs, but is developing a generic application safety case supporting a risk-commensurate approach to the adoption of such technologies [14-16]. Specifically, the approach can be summarized as supporting LCLCWDs with a level of safety integrity for “warning level crossing users of an approaching train” that is at least commensurate to the magnitude of risk reduction required to meet tolerable hazard rates for system hazards including “collision between road and rail vehicle”.

As a significant proportion of level crossing warning device costs are influenced by safety integrity requirements, this approach can support the adoption of substantially lower-cost warning systems, allowing more level crossings to be upgraded each year for a given budget. Interfacing LCLCWDs with ITS-based in-vehicle warning technology is a logical step in providing a cost-effective improvement to level crossing safety. A holistic approach to level crossing safety is essential, where both the proposed strategy and low-cost level crossing research can support a larger strategy for a consistent and comprehensive approach to level crossing improvement. The key components of the first strategy include:

Further research to provide evidence for the specification of industry-wide standards:
- HMI design for effective presentation of information to the road user including: effective communication of system state (i.e. for failure states), optimal warning times, sensory method to best impart warning information, etc.;
- Investigation of adoption strategies for the technology. This should include engagement with vehicle manufacturers and investigation of government mandated installation for high risk vehicles, etc.;
- Development of a safety argument addressing requirements for reliability and integrity; and
- Development of an economic argument based on the various adoption strategies.

Development of draft performance-based standards for an in-vehicle level crossing warning application:
- Definition of warning functions, operating principles, where intelligent warnings are based on proven human factors principles and applied in context;
- Specification of reliability and integrity targets; and
- Human factors rules and methods to support an integrated application design for a multi-application environment.

Large test-bed deployment:
- Facilitation of a test-bed deployment with the objective of collecting a substantial amount of data to support an argument for wide-spread adoption;
- Review of the draft standards based on data and evidence from the test-bed; and
- Lobbying state / federal governments for appropriate support and legislative change to facilitate a nationally consistent approach to adoption. The support aspect includes development of an appropriate framework for accreditation of suppliers and application developers.

While the first strategy is conservative in its approach, it is not intended to preclude other approaches such as the use of train to vehicle communications. Due to the complexities of such paradigms, as discussed earlier in this paper, we believe that further research would be needed to determine the impact on human performance and to establish how appropriate levels of reliability could be achieved. The longer-term strategy addresses the need for additional research in order to support an evidence-based approach to the implementation and adoption of such paradigms. Key research components of the strategy include:

- Investigation of reliability and integrity aspects of innovative communications and technology paradigms including V2V and train to vehicle communications;

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• Investigation of technology evolution and how innovative communication paradigms can complement the previous strategy – e.g. train to vehicle communications used to provide a train approach warning at level crossings with passive controls, and as an additional safety control in case of I2V failure;
• Research into the potential use of existing vital train on-board location determination systems (used to support train protection and control functions in ERTMS, ATMS, and other in-cab ATP systems) for the provision of train approach warnings at level crossings;
• Research into optimal human factors design for innovative technology paradigms; and
• Research into overreliance issues associated with the provision of a train approach warning at level crossings with passive controls, providing evidence to inform design and potentially appropriate reliability and integrity targets.

5. IN-VEHICLE LEVEL CROSSING WARNING SYSTEM BASED ON AN I2V COMMUNICATIONS PARADIGM

This section describes the vision for an in-vehicle level crossing warning system based on an infrastructure to vehicle (I2V) communications paradigm. Conceptually, the railway provides a vital train approach indication (and potentially other information) to a road-side controller, which interfaces to a road-side unit that facilitates communications between the infrastructure and the vehicle.

5.1. Rail-side to Road-side Communication Standards

The proposed approach involves the use of established standards for traffic light synchronization between rail and road subsystems to provide the interface between the vital level crossing equipment and the road-side unit for the in-vehicle warning system. Current practice for traffic light synchronization in some jurisdictions in Australia involves the use of a linking cable between the vital level crossing equipment and a traffic controller. The connection from the level crossing equipment is installed in accordance with an approved railway design typically involving suitable levels of isolation and surge protection, minimising risk to railway equipment from failures, surges, inductions or lighting strikes. In a draft Victorian standard on level crossing infrastructure [17], responsibilities in relation to the interconnection of rail and road systems for traffic light coordination are defined, noting that connections in the traffic controller are to be made by the road authority. Precedence for such interconnections and a clear division of responsibility are strong arguments in support for this approach.

The above interconnection method only provides a simple logic input to the traffic controller indicating protection state of the level crossing. As an interim solution, it provides a relatively low-cost method to interface ITS I2V communications infrastructure to vital railway systems. There is however, an opportunity to provide greater levels of information from the railway infrastructure to facilitate more “intelligent” warnings. Using standards such as IEEE 1570: Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection [18] for interconnection between rail and road systems, additional information including level crossing operating state, wayside equipment state, train movements (direction, speed, estimated arrival and departure times) and other user-defined information can be provided to the traffic controller.

This standard defines logical and physical interfaces and performance attributes for interconnection between rail and road systems at level crossings. A high level illustration of the interface between the two systems is illustrated in Figure 1.

![Figure 1. IEEE 1570 based approach](image)

The wayside equipment gateway would provide a vital train approach indication (and other relevant information) to the road subsystem. Railway operators would be responsible for the installation, commissioning and maintenance of this component as part of the level crossing.

In order for railway operators to meet duty of care obligations under the national rail safety legislation (subdivision 2 – duties, section 52) [12], they would need to ensure that this component and its interfaces to existing level crossing equipment are safe so far as is reasonably practicable. As part of the approval of such equipment (i.e. the wayside equipment gateway), evidence of functional and technical safety would typically be provided in a technical safety report that includes evidence of safety analyses, design principles and technical principles that assure safety of the design [19-23].

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Designers, manufacturers and suppliers of such equipment also have obligations under the national rail safety legislation (section 53 – duties of designers, manufacturers, suppliers, etc.)[12] to ensure that the equipment is safe if used for the purpose for which it is designed so far as is reasonably practicable.

As the railway would only be responsible for the vital train indication provided by the wayside gateway, its responsibility would theoretically be delineated from the road subsystem (as in current traffic light synchronization scenarios), which operates within a very different legal and regulatory landscape. In contrast to the legislative requirements for safety in the rail environment, road safety legislation typically relates to individuals where road users are prosecuted for dangerous driving, use of a vehicle that is not road worthy, etc.

The advanced transportation controller gateway (part of the road subsystem) would communicate with the wayside gateway via the IEEE 1570 interface. The transportation controller could also be used to communicate state information (e.g. level crossing equipment failure) to the road operations system, facilitating timely notification of traffic police. Temporary closure of a level crossing could also be propagated via real-time traffic congestion update systems (traffic services used by GPS navigators), re-routing road users to avoid a temporarily closed level crossing.

Road authorities would be responsible for installing, commissioning and maintaining this component as part of the road subsystem. While outside of the scope of this paper, issues such as appropriate levels of remote monitoring and alarming for road authorities would need to be considered. It is assumed that road-side components including the dedicated short range communications (DSRC) road-side unit would be developed to appropriate road safety standards.

Responsibility in case of failures of the interface between road and rail infrastructure would be defined in safety interface agreements, minimising the potential for cross-jurisdictional disputes. Having a good technical interface specification is also essential and will lead to a clear allocation of organizational responsibility.

Having centralised monitoring and maintenance functions for ITS infrastructure is likely to reduce the impact of local council resources. Issues of additional organisational complexity and cost need to be taken into consideration as part of the systemic costs for implementation of an in-vehicle warning system.

5.1.1. I2V communication standards

A standards-based approach for infrastructure to vehicle (I2V) communications forms part of the proposed approach. There is currently an international effort to standardize a vehicular communication platform (DSRC) to support a range of applications from safety to value added services. Safety applications include the provision of warnings for unsafe conditions and imminent collisions; value added services include electronic payment for tolling and the provision of real time accident and congestion information.

By supporting a standardized communication platform, an open, competitive multi-vendor market can be facilitated. It is expected that vehicle manufacturers will provide a GPS and DSRC-enabled multi-application environment in future vehicles. The key standards for DSRC are the IEEE 1609 suite of standards, the DSRC message set standard SAE J2735, and minimum performance requirements standard SAE J2945.1 to support DSRC applications. Note that some of these standards are still under development.

Spectrum allocation is also an ongoing issue in Australia, where the Australian Communications and Media Authority (ACMA) is working on proposals for introduction of ITS at 5.9GHz [24], however there are issues relating to existing users of the frequency and adjacent frequencies that need to be addressed.

5.1.2. I2V communication reliability

One of the challenges in providing a safe in-vehicle warning system is ensuring that failure of communications does not result in unsafe states (e.g. the road user is not warned when a train is approaching). This is complicated by the fact that the WAVE Short Message Protocol (WSMP) broadcasts short packets in an un-acknowledged delivery mode.

In the case of a communication failure affecting the in-vehicle warning as an overlay to an existing vital train warning system, the crossing would be protected by the existing level crossing infrastructure minimising the consequences of an in-vehicle warning failure. The proposed I2V strategy does not include train to vehicle communications, where the risk of failure at a level crossing with passive controls would be substantially higher for the reasons discussed earlier in this paper. Further research and investigation into the use of train to vehicle communications for in-vehicle warnings forms part of the longer-term strategy.

While DSRC provides various protections against threats to message integrity, reliability of safety-related communications to a large extent needs to be managed at the application layer. The on-board unit would not know when to expect broadcast messages from road-side units, and therefore would not know whether a given road-side unit has failed. Assuming a vital train approach indication is
provided to the advanced transportation controller gateway, the challenge is to ensure reliable communications between the DSRC road-side unit and the DSRC on-board unit, given the asynchronous messaging paradigm.

To determine appropriate targets for integrity and reliability of communications, an analysis of threats to communications and the hazards they lead to should be conducted. As I2V communications operate on open channel, malicious threats against these communications (e.g. spoofing, modification, replay and jamming / denial of service) also need to be considered. Of particular importance is the ability to authenticate the source of the messages (cryptographic authentication) and ensure they have not been modified (cryptographic integrity). The standard IEEE 1609.2 [12] describes the DSRC security services and defines methods to secure DSRC management and application messages.

5.1.3. Level crossing warning application

In addition to the reliable messaging provisions discussed in the previous subsection, the key functions of the level crossing warning application need to be defined, including those that are safety-related. While the DSRC standards provide the communications and messaging layers, no level crossing warning application has been defined. As part of the I2V level crossing warning strategy described in this section, it is proposed that a committee of rail and road stakeholders develop a functional specification for a level crossing warning application, which would be based on a thorough analysis of the human factors issues involved. The specification would also include data (e.g. speed, location, heading of vehicle / train) and performance (e.g. update rate, accuracy, safety, etc.) requirements to support the application.

One possible approach to determining appropriate warning functions involves mapping them to those provided by existing infrastructure, such that human factors issues discussed earlier in the paper including competing and inconsistent warnings are effectively controlled. Robust and congruent warning methods are key to user acceptance and confidence in ITS. Integration of human capabilities and limitations in the system design and technical specifications will ensure that the information provided by DSRC is intuitive, timely, relevant, consistent and most importantly, able to be perceived and acted upon.

A possible function mapping for level crossings with active controls is detailed in the following table.

<table>
<thead>
<tr>
<th>Function</th>
<th>Existing LX</th>
<th>In-vehicle application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train approach warning (AS 1742.7 compliant)</td>
<td>Activation of flashing lights; Lowering of boom barriers</td>
<td>Provide “Train approach” warning to road user; Inform road user of multiple trains</td>
</tr>
<tr>
<td>Failure mode</td>
<td>Currently equivalent to train approach warning</td>
<td>Failure state warning; Possibility to advise road user when level crossing restored to normal operation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function</th>
<th>Existing LX</th>
<th>In-vehicle application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning of presence of LX</td>
<td>Passive signs, road markings compliant with 1742.7 [25]</td>
<td>Prepare to stop and look both ways for trains</td>
</tr>
</tbody>
</table>

A pre-warning approach function was considered (similar to the steady amber phase in the UK); however, the potential for the warning to encourage road users to engage in risk taking behaviour (i.e. beat the train) needs to be further analysed to determine whether this function would be beneficial in the Australian context, and whether the pre-warning could be processed by the in-vehicle system, taking into consideration the vehicle’s speed and location to provide a context-appropriate pre-warning.

In addition to providing consistent functional mappings, there is an opportunity to provide an enhanced and targeted level of information to road users with in-vehicle warning systems. In particular, the warning application can mitigate some of the deficiencies of the current level crossing design. An example of this is where a level crossing is in a failure state (i.e. continuous ringing). The level crossing application can provide relevant information to road users as to the state of the level crossing and what actions to take in this situation (e.g. not to traverse, suggestion of an alternative route). While further research is needed to determine how best to communicate state information, such functionality could potentially reduce risks associated with mode confusion.

A possible function mapping for level crossings with passive controls is detailed in the following table.

<table>
<thead>
<tr>
<th>Function</th>
<th>Existing LX</th>
<th>In-vehicle application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning of presence of LX</td>
<td>Passive signs, road markings compliant with 1742.7 [25]</td>
<td>Prepare to stop and look both ways for trains</td>
</tr>
</tbody>
</table>

The application design should address the following key issues:

- The application needs to provide a clear indication to the road user of the system’s failure modes. A formal analysis such as Failure Mode Effect and Criticality Analysis (FMECA) should be used to determine failure modes, how they are detected and how they will be manifested in the HMI.
- Design of the HMI, being a critical aspect of the level crossing warning system, needs to consider the most effective methods to warn
and advise the road user. Refer to the discussion on HMI in Section 3.1.1.

- The application needs to consider how to manage an internal database of level crossings given that warnings will need to be provided for 100% of level crossings, whether they are with active or passive controls. As data contained within this database is used by safety-related functions of the application, special consideration needs to be given to assuring integrity and accuracy of the information contained within.

- Safety needs to be considered in the application lifecycle from the specification of requirements to software design, development and validation activities. This includes an analysis of hazards and risk, specification of safety requirements and in particular, use of appropriate tools and methods for managing systematic failure. The Motor Industry Software Reliability Association (MISRA) has developed a suite of guidelines for integrity and safety analysis for vehicle-based software. Further investigation is required to determine how safety integrity requirements can be met within a multi-application environment.

- An often-overlooked aspect in determining overall safety is the holistic environment into which new technology is introduced. The unfettered introduction of after-market units that do not integrate into current platform systems, especially with regard to multi-applications, may actually decrease overall road/rail safety and therefore not be the best strategy.

6. CONCLUSION

This paper has discussed the benefits and challenges for the adoption of ITS-based in-vehicle level crossing warning systems. Such systems have the potential to provide a significant improvement to safety; however, without considering the technical, human factors and legal implications of the various approaches to design, implementation and adoption, the technology has a limited chance of gaining widespread acceptance.

Two ITS development strategies were proposed: the first, a short/medium term strategy with the view of finding a pragmatic way forward within current legal and regulatory frameworks, and addressing recommendations from the Kerang inquiry; and the second, a longer-term strategy investigating the more complex communication paradigms and deployment contexts with a focus on human factors and technical research.

In-vehicle warning systems for level crossings are likely to provide the framework for future systems, which highlights the importance of ‘getting it right’. Both technical and human factors issues must be addressed if it is to provide the significant potential advantages and performance envisaged. It is undesirable to have these facets developed in isolation and a smarter approach is to integrate human factors into the technical solution.

7. ACKNOWLEDGEMENTS

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8. REFERENCES


