Towards the Adoption of Low-cost Rail Level Crossing Warning Devices in Regional Areas of Australia: A Review of Current Technologies and Reliability Issues

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Abstract

This paper discusses major obstacles for the adoption of low cost level crossing warning devices (LCLCWDs) in Australia and reviews those trialed in Australia and internationally. The argument for the use of LCLCWDs is that for a given investment, more passive level crossings can be treated, therefore increasing safety benefits across the rail network. This approach, in theory, reduces risk across the network by utilizing a combination of low-cost and conventional level crossing interventions, similar to what is done in the road environment. This paper concludes that in order to determine if this approach can produce better safety outcomes than the current approach, involving the incremental upgrade of level crossings with conventional interventions, it is necessary to perform rigorous risk assessments and cost-benefit analyses of LCLCWDs. Further research is also needed to determine how best to differentiate less reliable LCCLWDs from conventional warning devices through the use of different warning signs and signals. This paper presents a strategy for progressing research and development of LCLCWDs and details how the Cooperative Research Centre (CRC) for Rail Innovation is fulfilling this strategy through the current and future affordable level crossing projects.

Keywords

Rail level crossings; Low cost; Level crossing warning devices; Reliability

1. Introduction

In the period between 1996 and 2000, it is estimated that approximately 36 crashes per year occurred at passive level crossings throughout Australia (Cairney, 2003). These crashes resulted in an average of four deaths and six serious injuries per year. Passive level crossings represent 67% of the 8,838 public level crossings in Australia (Railway Industry Safety and Standards Board, 2009).

It is estimated that the annual cost of collisions in Australia is approximately $24.8 million AUD, $8.3 million of which is attributable to passive crossings (Cairney, 2003). . These figures exclude costs to the rail owner and operator, which often can amount to several million dollars for a single crash.

Providing active control at a passive level crossing eliminates the need for the road user to make a decision and as such, is the most obvious and common improvement made. According to estimates by (Elvik et al., 2009), based on a number of international before and after studies, the addition of a flashing lights and sound signals at level crossings that previously had warning signs, was estimated to reduce the number of accidents by 51%. The addition of barriers was estimated to further reduce the number of accidents by 45%. Based on these estimates, the installation of sound and light signals has the potential to greatly reduce the number of accidents on passive level crossings. Based on an estimate of between $200,000 and $300,000 AUD excluding maintenance costs, the cost of installing active protection at all passive level crossings in Australia would be between $1.2 billion and $1.8 billion AUD (Cairney, 2003). In addition, ongoing maintenance costs would be significant, especially for passive level crossings in remote locations.

In the state of Victoria, for example, an annual budget of $6 million AUD has been allocated to the level crossings upgrade program (Jordan, 2006). Given that there are approximately 1060 passive level crossings on active lines in Victoria as of April 2010, a low cost level crossing warning device costing 20% of conventional systems, would allow a significantly greater number of level crossings to be treated. Such systems are not intended to replace existing systems, rather provide an additional control to improve the conspicuity of selected passive level crossings.

Low cost level crossing warning devices (LCLCWDs) are generally characterized by the use of alternative technologies for train detection and connectivity, with the objective of reducing the cost of equipment, installation and maintenance.

Since the coronial inquests in Victoria more than 20 years ago (Johnstone, 1989), recommending the urgent consideration and implementation of low-cost alternatives for protecting level crossings, the rail industry has struggled to move forward on the adoption of LCLCWDs due to a number of legal and technical obstacles.

In particular, legal liability issues exist with the adoption of LCLCWDs that do not meet the safety integrity levels of conventional crossings. As the legal responsibility of level crossings is typically placed with rail infrastructure managers, practitioners are concerned with the potential liability arising from fatalities or injuries occurring at level crossings protected with this technology. This is especially the case if such fatalities or injuries are due to the failure of the technology, where road users expect warnings to behave with the same reliability as conventional warnings.

The current approach to the protection of level crossings is the incremental upgrade of passive crossings to conventional active protection systems, where available investment for upgrading sites is prioritized using the Australian Level Crossing Assessment Model

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(ALCAM) (Department of Transport NSW, 2010). This model provides jurisdictions with the ability to rank level crossings using a consistent basis according to a detailed level of comparable risk, exposure and consequence as well as determining the cost-effectiveness of various treatments.

The argument for the use of LCLCWDs is that for a given investment, more passive level crossings can be treated, therefore increasing safety benefits across the rail network. This approach, in theory, reduces risk across the network by utilizing a combination of low-cost and conventional level crossing interventions, similar to what is done in the road environment. Rigorous risk assessment of LCLCWDs is needed in order to determine whether such technologies can be effective in reducing risk or whether reduced reliability can have a counter-productive effect on safety, compared with the incremental upgrade approach.

This paper discusses major obstacles for the adoption of LCLCWDs and reviews LCLCWDs trialed in Australia and internationally. This paper also presents a strategy for progressing the research and development of LCLCWDs, and explains how the Cooperative Research Centre (CRC) for Rail Innovation is fulfilling this strategy through the current and future affordable level crossing projects.

2. Major Obstacles for the Adoption of Low-cost Rail Level Crossing Technology

The following subsections discuss legal and technical obstacles for the adoption of LCLCWDs.

2.1. Legal Implications of the Use of Low-cost Rail Level Crossing Technology

It has been recognized that the determining factor for the acceptance of LCLCWDs by railway practitioners is the issue of legal liability. Of specific concern is Tort liability, which has been the principal motive for which LCLCWDs have not been adopted in other countries including the United States. (Roop et al., 2005) states that:

"…if railroads (or any entity taking responsibility for risk at crossings) install equipment at a grade crossing that is in any way inferior to current technology – independent of cost – then liability will likely be maintained because the responsible entity knows that the alternative system is not as good as an existing system – an act of commission."

(Roop et al., 2005) further notes that Tort liability reform is a necessary precursor to change and that changing the apportionment of risk and liability may facilitate movement towards the acceptance of new technology that can demonstrate an overall enhancement of safety. Recent progress has been made in Australia through the introduction of Safety Interface Agreements (SIAs) (Public Transport Safety Victoria, 2009), which define the responsibilities of rail infrastructure managers and road managers for rail level crossings. In particular SIAs serve to:

- clearly identify all relevant interfaces;
- clarify roles and responsibilities between rail infrastructure managers and the road authority;
- create consistent, common approaches to road/rail interface risks; and
- improve the safety measures at level crossings through the management of safety risks.

The current state of safety legislation and SIAs in Australia is summarized by (Spicer, 2010). He notes that apart from Western Australia and Northern Territory, which have rail safety bills awaiting passage in parliament, the other Australian states, with the exception of South Australia, have enacted rail safety bills that contain SIA provisions. South Australia is planning to introduce amendments to the their rail safety legislation by November 2010.

The use of alternative technologies in level crossing warning devices increases the risk of liability when the technology is not fail-safe and is known to have caused a rail accident, where the use of a failsafe technology would have most likely prevented the same accident (Patterson, 2008).

The Road Safety Committee of the Parliament of Victoria during the inquiry into improving safety at level crossings, determined that low-cost warning systems are not, nor should be a replacement or substitute for fail-safe level crossing controls (Road Safety Committee Parliament of Victoria, 2008). Instead it was recommended that such technologies be used as a supplement or enhancement to existing controls at level crossings, in particular passive crossings. The lack of fail-safety in low cost warning technologies was not considered to be a sufficient reason in itself for their rejection, as they can potentially provide greater levels of protection than currently available at passive crossings.

(Jordan, 2006) notes that legal advice received before the trial of LCLCWDs in Victoria was of the view that the technology had to be well tested, subjected to rigorous risk assessments, and applied in a professional manner. If this was done, it was concluded that a Court of Law would most likely have little reason to find against the new device, all other matters being equal.

This appears consistent with the response from the director of Public Transport Safety Victoria in a letter to the chair of the Victorian Railway Crossing Safety Steering Committee, responding to a request for an opinion from the regulator on whether the adoption of LCLCWDs would be prohibited by the Rail Safety Act 2006 (Osborne, 2007). He states:

> "The Rail Safety Act 2006 (RSA) requires Accredited Rail Operators (AROs) to eliminate risks and where this is not possible to reduce those risks to a standard of 'so far as is reasonably practicable'. […] If the technology being considered achieves risk to be eliminated or reduced so far as is reasonably practicable, then prima facie it could be utilized consistently with the RSA".

The Victorian Road/Rail Safety Interface Agreements Rail safety guidelines (Public Transport Safety Victoria, 2009) provide practical advice on what is expected by the Safety Director for those with obligations under the Rail Safety Act (Victorian Parliament, 2006). This document specifically defines risk management obligations for the use of new technologies in cost-effective warning systems. It states that section 50(7)(d) of the RSA requires rail operators to document the range of risk control measures considered when managing risks to their operations, state their viability and effectiveness and specify their reasons for selecting certain control measures and rejecting others. It is further stated that where rail operators and road managers have identified risks in respect of passive crossings, they will need to conduct a full assessment of potential control measures.

It is noted that Public Transport Safety Victoria (PTSV) supports the introduction of cost-effective new or alternative technology which will reduce risks at level crossings, if the systems used are of high reliability and represent the best controls in the circumstances.
The PTSV has indicated that it would expect reliability performance at least equal to that of current road traffic signals (McKeown, 2008).
Research is needed to demonstrate that the approach of upgrading a large number of passive level crossings with less reliable LCLCWDs would improve safety over and above the current incremental upgrade approach. If this can be demonstrated, legislation would need to accommodate LCLCWDs, such that rail infrastructure managers cannot be held liable for the device's reduced reliability, assuming there is no negligence involved.
Infrastructure operators may be able to justify the adoption of LCLCWDs before such legislative reform if they can demonstrate that risks have been reduced so far as is reasonably practicable. The National Rail Safety Guideline on the Meaning of Duty to Ensure Safety So Far As Is Reasonably Practicable (SFAIRP) (Salter, 2008) provides assistance to duty holders with the interpretation of the SFAIRP legislative qualification and provides practical guidance for demonstrating that the cost of additional measures to control risk over and above those already in place would be grossly disproportionate to the benefit of the risk reduction associated with the implementation of the additional risk control. In determining what is reasonably practicable, it is expected that appropriate persons will make a direct judgment based on a qualitative assessment of costs and benefits. (Salter, 2008).

2.2. Required Reliability Levels for Active Level Crossing Protection Systems

LCLCWDs are generally characterized by the use of alternative technologies for train detection and connectivity. Conventional level crossing warning systems typically use intrinsically safe train detection technologies and control systems, such that the system as a whole meets a tolerable level of risk of dangerous failure, stated in the form of a discrete safety integrity level (SIL).
Current best practice is to make use of Safety Integrity Levels (SILs) to control systematic failures (Rail Safety and Standards Board, 2007). SILs specify the safety integrity requirements of the safety functions allocated to safety-related systems and represent different levels of rigor in the development process.
Safety integrity is defined as the probability of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a stated period of time (Standards Australia, 1999b) (CENELEC - European Committee for Electrotechnical Standardization, 2003).
Five SIL levels are defined: SIL4 to SIL1, SIL4 being the most stringent; and SIL0, which has no target probability as it essentially associated with functions not relied on to control risk. Table 1 details the SILs for continuous mode operation.

Table 1. Safety integrity levels (Standards Australia, 1999a)

Safety integrity level	**High demand or continuous mode of operation** (Probability of a dangerous failure per hour)
4	$\geq 10^{-9}$ to $< 10^{-8}$
3	$\geq 10^{-8}$ to $< 10^{-7}$
2	$\geq 10^{-7}$ to $< 10^{-6}$
1	$\geq 10^{-6}$ to $< 10^{-5}$

Conventional level crossings are commonly required to meet SIL4 and are described as having a fail-safe design.
The term "fail-safe" is often confused with "fail-to-safe". Fail-safe is a design philosophy applied to safety-critical systems, such that the result of a failure either prohibits the system from assuming or maintaining an unsafe state, or causes the system to assume a state known to be safe. Systems that are fail-safe typically implement suitable levels of redundancy in order to meet a designated SIL. The term "fail-to-safe" refers to the behavior of a system during failure, such that the failure is right-side rather than wrong-side.
In right-side failure, the resulting state of the system is safe overall. In the context of rail level crossings, a failure would result in the activation of the crossing's warning signal (i.e. flashing red lights or other failure mode warning) until the failure is resolved.
In contrast, a wrong-side failure (dangerous failure) is a failure condition that results in an unsafe state. An example of this type of failure in the context of rail level crossings, is the missed detection of an approaching train, where the crossing's warning signal is not activated. Such failures could significantly increase the risk of an incident.
As the target cost for LCLCWDs is in the range of $50,000 to $100,000 AUD (Wallace et al., 2010), SIL4 certified technology is not likely to fall within this range. Technology used in LCLCWDs should, however, be required to provide a fail-to-safe capability, ensuring that failures are not wrong-side but right-side. A lower SIL target may be practicable if risk assessment determines that the risk of a reliability-related hazard occurring on a level crossing with a LCLCWD developed to a lower SIL is tolerable and the cost of developing to higher SILs is grossly disproportionate to the benefit of the risk reduction.
Research is needed to determine how best to differentiate less reliable LCLCWDs from conventional warning devices (e.g. through the use of different warning signs and signals). An important aspect of this research is the investigation of how different types of failure (both right-side and wrong-side), and expressions of these failures, impact road user behavior, and ultimately road user safety.
Another obstacle to the adoption of LCLCWDs is the type approval process. Obtaining type approval for such technologies is difficult due to the lack of data on operational history and long-term reliability. A typical type approval process involves evaluation of a product taking into consideration issues such as functionality, compliance with established standards, performance history, RAMS (reliability, availability, maintainability and safety), and life cycle costs and benefits (RailCorp, 2010). A trial installation is common practice where relevant data on operational history in Australia is not available. Such trials subject the product to periods of normal operation and

intermittent periods of abnormal operation including failure conditions. Continuous monitoring and logging provide data that can be used for the evaluation of the product.
Due to the myriad of alternative technologies used for train detection in LCLCWDs (Tey et al., 2009), the development of an evaluation criteria for new technologies used in LCLCWDs would be useful in determining whether conducting a costly and lengthy type approval process is viable. At this time, we are only aware of the efforts of VicTrack in developing a new technology evaluation scheme to facilitate the type approval of new technologies (VicTrack Access, 2010b). VicTrack are developing the evaluation process on behalf of the Victorian Railway Crossing Technical Group (RCTG), which is one of four sub-committees of the Victorian Railway Crossing Safety Steering Committee (VRCSSC). This scheme takes a holistic approach to evaluation, comparing aspects including life cycle cost, quality, safety, maintenance and infrastructure compatibility (VicTrack Access, 2010a) .
Due to cost constraints, it is probable that LCLCWDs will not have a SIL certification. As such, evidence that the development process for a given LCLCWD has been guided by safety standards (Standards Australia, 1999a) (CENELEC - European Committee for Electrotechnical Standardization, 2003) and that appropriate technology and architecture options have been used to meet the target SIL and reliability requirements, would be fundamental if such LCLCWDs are to gain acceptance.
A reliability criteria and operational data for LCLCWDs using alternative technologies would allow rail practitioners to reject non-compliant systems and potentially expedite type approval of candidate LCLCWDs. Rail infrastructure managers could therefore adopt LCLCWDs earlier using accepted risk management processes to demonstrate that the risk for a given rail level crossing has been reduced so far as is reasonably practicable.
The following subsections discuss current trials of LCLCWDs, how concepts in the trials technologies can be adapted to the Australian context.

3. Low-cost Level Crossing Warning Device Trials

This section reviews LCLCWD technologies that have been or are currently being trialed. Information on LCLCWD trails is very limited. This review is based on publically available information that was found for the trials that we are aware of. Prototype and concept LCLCWD systems are not discussed in this paper. Figure 1 illustrates different types of active warning signs used or proposed for use with the reviewed LCLCWDs.

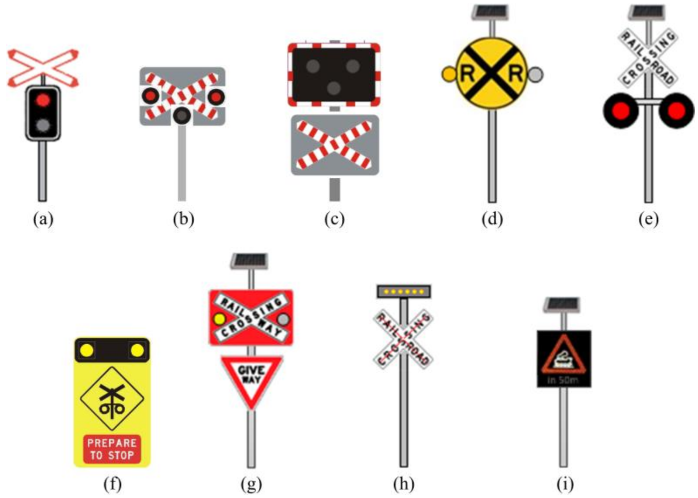

Figure 1. Active Warning Signs

3.1. MICRO Level Crossing Specification (Switzerland)

MICRO represents the Swiss national effort to develop a low-cost level crossing warning system specification applicable to level crossings with a single track and limited traffic. From 2006 to 2007 a pilot system was in operation, the results of which were used to develop the final MICRO design.
In May 2008, applications to ASTRA (Swiss federal roads office) and BAV (Swiss federal office of transport) were tabled in order to obtain approval of the MICRO concept and necessary ordinance changes. By the end of July 2008, there was approval from ASTRA and agreement from BAV to proceed with the addition of provisions for the MICRO concept in the EBV (Eisenbahnverordnung - rail regulation) and AB-EBV (Ausführungsbestimmungen zur Eisenbahnverordnung – design rules for railway ordinance) (Kommission Technik und Betrieb Schiene Fachgruppe Elektrotechnik Arbeitsgruppe Bahnübergänge, 2009).
In January 2009 the VöV (union of public transports) published the MICRO technical specification with reservations. Version 2.1 of the MICRO technical specification (Groupe d'experts en électrotechnique and Groupe de travail passages à niveau, 2010) was released on the 18th February 2010 with a letter from the Swiss public transport union (Vollmer and Walser, 2010) noting that regulatory approval for the MICRO design had been obtained from the EBV, AB-EBV and SSV (Signalisationsverordnung - road signs regulation). The letter further mentions that several manufacturers have started development of systems based on the MICRO design, and that several methods for type approval are in process. Railway companies were notified of commissioning from the enactment of assessed regulations July 1, 2010 and that applications for planning approval could be submitted.

Interestingly, in 2009 the MICRO warning consisted of tricolor traffic lights (red, yellow and greed), where a steady green light indicated that the level crossing was free, a steady red light indicated that the level crossing was occupied, and no light or a yellow flashing light indicated that the level crossing was out of operation (Kommission Technik und Betrieb Schiene Fachgruppe Elektrotechnik Arbeitsgruppe Bahnübergänge, 2009). Subsequently this was changed to a bicolor traffic light, as described in the MICRO technical specification (Groupe d'experts en électrotechnique and Groupe de travail passages à niveau, 2010).

The MICRO concept may prove to be a valid starting point for an Australian specification, however the MICRO design would need to be adapted to support the use of solar power and potentially reduced safety requirements if the cost is to remain within the $50,000 - $100,000 AUD target.

The table below summarizes the characteristics of the MICRO design as detailed in the specification.

Table 2. MICRO specification V2.1f (Groupe d'experts en électrotechnique and Groupe de travail passages à niveau, 2010)

Target Operating Environment	
Crossing type:	Single track only
Train speeds:	$V_{max} \leq$ 100kph
Road / rail volumes:	PA / hour ≤ 2 (PA = Equivalent Persons)
Target cost:	approx. € 55.000,00 (75.000,00 CHF)
Reliability	
Target rate of dangerous failure of protection system:	SIL3
Fail-to-safe capability:	Yes, however missed train detection results in wrong-side failure. Intrinsically safe activation points reduce likelihood of missed train detection. If after activation, triggering does not involve rail traffic, warning switches to flashing yellow (fault mode) after at least 30 seconds.
State of warning provided to train driver:	No. (same railway operation rules as passive crossings apply)
Remote diagnostics:	No supervision of equipment from a control center; Equipment failure is communicated to maintenance.
Technical Characteristics	
Train detection:	At least 2 intrinsically safe activation points and 1 deactivation point. (No specific technology prescribed)
Connectivity:	Cables
Warning activation time:	≥ 18 seconds (3 seconds of flashing yellow, 3 seconds of yellow and 12 seconds of red)
Warning release time:	After passage of train, red light switches to flashing yellow and after 3 seconds lights off.
Warning	
Active warning type:	Bicolor traffic lights (red and yellow) with a mast and St. Andrew's cross. (Figure 1a)
Failure mode warning:	Yellow flashing lights (both sides)

3.2. New SAL0 Type Level Crossing System (France)

This project represents the French effort to develop a low-cost level crossing warning system targeted at existing passive level crossings with a degraded mode that is easily understandable by road users. SAL0 is a type of automatic level crossing with warning lights and audible warning, but without barriers.

The project was officially launched in October 2007 with a working group including RFF (Réseau Ferré de France – French railway owner and manager) and SNCF (Société nationale des chemins de fer français - National French Railway Company) (Feltz, 2008). In 2009 field testing of 2 or 3 different types of level crossings was scheduled, followed by the definition and specific criteria (train speed, road traffic volume, visibility, etc.) for installation of the new type of crossing.

(Feltz, 2008) specifically notes that the degraded mode of SAL0 will not be "managed" by the railway, but by the road user. In order to facilitate this, the failure mode of the warning is visualized by a fixed white light on the warning signs containing a St. Andrew's cross and an additional stop sign, illuminated only in failure mode.

Table 3 summarizes the characteristics of the new SAL0 concept design based on the publicly available information to date.

Table 3. New SAL0 type level crossing (Feltz, 2008)

Target Operating Environment	
Crossing type:	Single track only
Train speeds:	45kph ≤ V ≤ 100kph
Road / rail volumes:	Undefined
Target cost:	≤ € 15.000,00 (Ghazel et al., 2007)
Reliability	

Target rate of dangerous failure of protection system:	≤ 1 miss over 10^6 operation cycles (Ghazel et al., 2007)
Fail-to-safe capability:	Yes, however missed train detection results in wrong-side failure.
State of warning provided to train driver:	No. (same railway operation rules as passive crossings apply)
Remote diagnostics:	Unknown
Technical Characteristics	
Train detection:	Axle detectors
Connectivity:	Wireless planned
Warning activation time:	Undefined
Warning release time:	Undefined
Warning	
Active warning type:	A St. Andrew's cross with 2 red lights flashing alternatively and a fixed white light to indicate failure mode. (Figure 1b and c)
Failure mode warning:	Fixed white light.

3.3. C3 Trans Systems HRI-2000 System (U.S.A.)

The HRI-2000 system is a low-cost active level crossing warning system that features an innovative design based on alternative technologies such as the Global Position System (GPS) and wireless communications for train detection and activation of crossings. The system was developed by C3 Trans Systems, led by the Minnesota Department of Transportation (URS Corporation and TranSmart Technologies Inc., 2005).

In this system, locomotives are fitted with a location-determination subsystem based on GPS with dead reckoning, ensuring that the locomotive's position can be reliably determined in case of short-term obscuration or outage of the GPS signal. Inputs for the dead reckoning are inertial (i.e. gyroscope) and wheel (e.g. odometer) measurements.

Advanced train detection is accomplished through the reception of a radio beacon transmitted by a locomotive at regular intervals containing location information. A level crossing within radio range (less than 5km) will be able to receive the beacon and initiate a data exchange with the locomotive. The crossing is activated when the approaching locomotive is a preset warning time away from the crossing, based on the locomotive's location and speed. Train detection sensors at the crossing ensure that the warning remains active while the train is at the crossing.

Should the locomotive fail to communicate with the level crossing, or the level crossing indicates that it is in a state of failure, the on-board system issues an alarm to the crew indicating that the crossing ahead is non-responsive. The crew can then stop on the approach to the crossing and manually flag the crossing before entering.

A field operational test was conducted for 80 days from the 23rd June to the 10th September 2005 at 27 crossings to determine whether the low-cost active warning system could perform with an equivalent if not better performance than conventional active warning systems at low traffic volume level crossings.

Of the 27 crossings, six were operated in active-mode the remaining in shadow-mode. The active-mode crossings were fully functional, where the warnings from the new warning device were apparent to the public. Table 4 summarizes the characteristics of the HRI-2000 system. The reliability of the system as described (URS Corporation and TranSmart Technologies Inc., 2005) is summarized in Table 5. Note that the terminology "failed encounters" refers to the failure of the system to successfully detect, activate and acknowledge the state of the warning device when the locomotive approaches the crossing. This may be caused by failures in GPS localization, communication, software, etc. "Activation false positives" refer to the train being incorrectly detected on the island by two post-mounted sensors consisting of a magnetometer and ultrasonic sensor, used to keep the warning active while the train is in the crossing. The sensors are also used as an auxiliary detection function for roll-away stock.

Table 4. HRI-2000 system (URS Corporation and TranSmart Technologies Inc., 2005)

Target Operating Environment	
Crossing type:	Single track only
Train speeds:	Range of speeds (radio range 5 km, crossings respond if distance between train and crossing < 2km)
Road / rail volumes:	
Target cost:	$10,000 to $15,000 USD (target) $40,000 USD (actual cost)
Reliability	
Target rate of dangerous failure of protection system:	Undefined. The system on-board the locomotive has levels of redundancy implemented, providing enhanced availability in case of subsystem failure.
Fail-to-safe capability:	Yes.
State of warning provided to train driver:	Yes. If fault, train would stop on the approach to the crossing and the crew would manually flag the crossing.

Remote diagnostics:

Technical Characteristics	
Train detection:	GPS / radio-based system for activation and 2 sensors, each consisting of a magnetometer and ultrasonic sensor) used to keep system active while train is on the crossing.
Connectivity:	Wireless (220MHz dedicated ITS frequency)
Warning activation time:	≥ 20 seconds (min 22 seconds, max 62 seconds, mean 34.4 seconds from field operational test)
Warning release time:	Undefined
Warning	
Active warning type:	(Figure 1d and e)
Failure mode warning:	Same as train approach warning

Table 5. HRI-2000 reliability for 3599 crossing events (URS Corporation and TranSmart Technologies Inc., 2005)

Train to crossing communication reliability:	96.2%
Communications between crossing equipment reliability:	Master to slave: 99.99%; Master to advanced warning sign 1: 99.39%; Master to advanced warning sign 2: 99.70%
Failed encounters:	77 (55 due to loss of GPS dead reckoning calibration, 15 due to intermittent radio communications, 7 due to other causes e.g. software bugs)
Activation false positives (non-locomotive activations):	301 (269 due to maintenance, 19 due to switch moves, 6 due to bad weather, 7 unidentified)
Activation failures:	No evidence of activation failures
System failures:	No system failures were reported
Fault notification failures:	No evidence of systems failures of faults
Fail-to-safe conditions:	7 (reasons unknown, 2 possibly attributable to severe thunderstorms)
Sensors at the crossing:	Magnetometers: 10 instances of train detection when train was more than 100m from crossing (4 due to slave magnetometer issue resolved by resetting the device, 6 due to switch maneuvers and maintenance activities). Ultrasonic sensor (secondary sensor activated by magnetometer): performed correctly
Solar / battery power reliability:	99.94% provided adequate power

3.4. HiLux (Australia)

VicRoads and VicTrack have been trialing LCLCWDs based on induction-loop technology since 1999, and have been evaluating the performance and reliability of the technology in shadow mode at St Johns Road in Creswick since 2003.

A three stage trial was conducted by VicRoads and VicTrack in partnership with Hi-Lux, a Melbourne-based contractor.

Stage 1 trial included the use of the following train detection devices: a Doppler radar unit, two magnometers, and in-train transmitter and an induction loop. (Jordan, 2006)

A Hi-Rail vehicle was used to travel along the track some 500 times over 4 days to check reliability of the detection devices. Based on the outcome of a risk assessment meeting that reviewed reliability results for each of the devices, the most reliable device was an electromagnetic induction loop detector provided by Hi-Lux Technical Services of Melbourne.

Stage 2 involved trialing a complete warning system comprised of a pair of induction loop detectors; a VHF radio link to signal train detection data to the control unit; and a control unit for the calculation of train speed and the activation of yellow flashing lights 25 seconds before the train was due to arrive at the crossing, regardless of speed. The trial was conducted on a section of unused track. During the trial, several hundred passes over the train detection devices were made with a Road Transferable Locomotive (RTL) to assess reliability of the system and to evaluate two road signal designs. After the trial, a risk assessment meeting concluded that the system needed a diagnostic remote monitoring device to enable verification of the system health and a diagnostic tool for self-checking on a regular basis.

In 2002 a stage 2A trial was undertaken to determine the reliability of the self-diagnostic equipment and other additions resulting from the stage 2 trial. Having completed this trial with good results, it was decided to take the system to stage 3. This involved trialing the system on a used passive site.

The system has been the subject of three risk assessments and has been successfully tested.

In 2004 the South Australia Department for Transport, Energy and Infrastructure Rail Services Section commissioned a project to determine the operational capabilities and reliability of the LCLCWD developed by Hi-Lux. The evaluation was undertaken on an active crossing at Monarto in South Australia as a closed trial, where the visual warning aspects of the LCLCWD were not made visible to the road user (i.e. shadow mode) (Department for Transport Energy and Infrastructure, 2005).

In the data collected from the trial, there were 19 right-side failures and 1 wrong-side failure in 4372 rail movement events through the crossing. After the trial, it was recommended that further evaluation of LCLCWD technology be undertaken at passive crossings, and that this is performed within a nationally coordinated approach to how and where LCLCWD technology could be applied.

In (Asia Pacific Rail Pty Ltd, 2006), it is noted that the system is required to be developed to SIL1. They argue that as the warning system is not the primary safety warning at the level crossing, the safety integrity of the software development and control is not required to be above SIL1. The primary safety warning would continue to be a stop sign at the passive level crossing.

It appears evident that if the active warning is provided at the crossing, the crossing becomes an active crossing to road users unless the warning is sufficiently differentiated from conventional warnings. As noted in (Asia Pacific Rail Pty Ltd, 2006), the placement of the warning signs is still under consideration due to potential legal issues associated with the consequences of failure for warning lights located at the crossing. They note that placement will be subject to a detailed risk analysis.

There is support for this low-cost warning concept from the Australian rail industry, as demonstrated in a letter from the chief executive officer of the Australian Rail Track Corporation (ARTC) to the chair of the Victorian Rail Crossing Safety Steering Committee in 2007 (Marchant, 2007). It was stated that the ARTC agrees such technology clearly has a place using As Low As Reasonably Practicable (ALARP) principles[2]. It was further noted that such technology would be approached on the basis that the warning device be separate to the existing control (e.g. a stop sign) and enhance it, so that if it fails, the original control remains in place. As the crossing remains passive, this approach limits the legal liability issues associated with installation of a low-cost intervention at the crossing.

It appears as though there are issues with the proposal to limit trains to 80kph. The ARTC mentioned in this letter that this constraint is unacceptable for them. Gaining acceptance of the technology may require support for higher speeds, and therefore greater risk reduction.

Table 6 summarizes the characteristics of the HiLux warning system. The reliability of the system as detailed in (Department for Transport Energy and Infrastructure, 2005) is summarized in Table 7.

Table 6. HiLux (Asia Pacific Rail Pty Ltd, 2006)

Target Operating Environment	
Crossing type:	Single freight-only tracks
Train speeds:	$V_{max} \leq 80$kph
Road / rail volumes:	≤ 6 trains / day
Target cost:	$50,000.00 AUD (Sinclair Knight Merz and VicTrack Access, 2008)
Reliability	
Target rate of dangerous failure of protection system:	SIL1
Fail-to-safe capability:	Yes, however missed train detection results in wrong-side failure.
State of warning provided to train driver:	No. (same railway operation rules as passive crossings apply)
Remote diagnostics:	Supported via phone link (Department for Transport Energy and Infrastructure, 2005)
Technical Characteristics	
Train detection:	3 pairs of magnetic induction loop detectors
Connectivity:	Cables and UHF data packet radio (400-500MHz)
Warning activation time:	Flashing lights are activated 25 seconds before train arrives. Can be extended if lights are located on road approach. In South Australia trial (Department for Transport Energy and Infrastructure, 2005), 30 seconds.
Warning release time:	Unknown
Warning	
Active warning type:	Two possible warning types are being considered: (Figure 1f and g) 2 flashing amber lights in an advanced warning sign from 50-200m from the crossing; and 2 flashing amber lights located within RX-11 configurations (AS1742.7) at the crossing, with the W7-4 level crossing logo replaced by the W7-7 Puffing Billy logo and the “PREPARE TO STOP” replaced by “LOOK FOR TRAINS”[3];
Failure mode warning:	Same as train approach warning

Table 7. HiLux comparative field trial at Monarto South for 4372 crossing events (Department for Transport Energy and Infrastructure, 2005)

Activation false negatives (missed train detection):	1 (wrong-side failure)
Fail-safe conditions:	19 (10 due to locked detector loops, 9 attributed to slow moving Hi-Rail or track maintenance vehicle in the detection zone). System reset to normal operation in all cases with the passing of the train over the cancellation loop.
Solar / battery power reliability:	Performed according to specifications.

[2] The ALARP principle is that the residual risk shall be as low as reasonably practicable. It has particular connotations as a route to reduce risks SFAIRP (so far as is reasonably practicable).

[3] Warning signs for HiLux are under review. The location of the warning lights has not been resolved and is subject to a detailed risk analysis due to the possible legal consequences in the event of failure (Asia Pacific Rail Pty Ltd, 2006).

3.5. O'Conner Engineering Train Detection System (U.S.A.)

In 2008, Sinclair Knight Merz was commissioned by VicTrack to investigate several LCLCWDs for applicability to the Victorian rail environment with a target total cost of $50,000 (Sinclair Knight Merz and VicTrack Access, 2008). Of the five products evaluated, only two were deemed suitable for trial: the Hi-Lux device based on induction-loop technology and the O'Conner device based on radar technology.

O'Conner train detection systems are currently installed in Sweden, Venezuela, Spain and private industrial railways in the U.S.A. The system was trialed by VLine in Victoria, however, was determined unsuitable due to issues including ineffectiveness of train detection around corners and on level crossings where there are obstructions in the approach (Upton, 2009). In addition, the cost of the system was determined to exceeded the target cost of 40% of a similar conventional level crossing warning system. Costs over the lifetime of the system would be similar to current conventional systems.

Table 8 summarizes the characteristics of the O'Conner radar train detection system.

Table 8. O'Conner Radar Level Crossing (Upton, 2009)

Target Operating Environment	
Crossing type:	Single track
Train speeds:	1kph to 80kph
Road / rail volumes:	Undefined
Target cost:	$100,000.00 AUD (40% of the cost of a similar basic level crossing) (installation exceeded this target)
Reliability	
Target rate of dangerous failure of protection system:	Not fail-safe; redundancy provided though monitoring by both detectors.
Fail-to-safe capability:	Unknown
State of warning provided to train driver:	Unknown
Remote diagnostics:	Unknown
Technical Characteristics	
Train detection:	2 Doppler radar sensors (24.125 GHz).
Connectivity:	Undefined
Warning activation time:	Activation time based on speed and timing sequence, assuming constant velocity. Required warning time 25 seconds.
Warning release time:	Undefined
Warning	
Active warning type:	Would conform to AS1742.7
Failure mode warning:	Same as train approach warning

3.6. EVA 1000 Warning Device (U.S.A.)

Project to test a LCLCWD manufactured by EVA Corporation of Omaha, Nebraska. The first official test site for the U.S. Federal Highway Administration (FHWA) was North Carolina, where the North Carolina Department of Transportation Rail Division entered into an agreement with the North Carolina and Virginia Railroad Company to field test the system.

The project was plagued with numerous systemic and weather-related problems that ultimately resulted in the termination of the trial (Jennings et al., 2005).

From October of 2001, the EVA 1000 system was to be evaluated for a period of three years as per the agreement with the FHWA. After some initial teething problems, requiring EVA personnel to install a new logic sensor and modify system parameters, the trial commenced. The system did not work satisfactorily, with large numbers of false activations and discrepancies in recorded train speeds. The system did not appear to have problems detecting trains. Other problems mentioned by (Jennings et al., 2005) include tail ringing (signals activating and deactivating as the train was pulls away from the railroad crossing), malfunction of the Train Directional Advisor, malfunction of the crossbuck displays and bulbs burning out.

In July 2003, a new EVA 3000 system was installed to address issues identified with the EVA 1000. The EVA 3000 was not able to be fully evaluated, as the system entered a fail-safe mode and was not able to be freed. By September 2003, the State of North Carolina decided to terminate the trial.

Table 9 summarizes the characteristics of the EVA 1000/3000 system.

Table 9. EVA 1000/3000 Warning Device (Jennings et al., 2005)

Target Operating Environment	
Crossing type:	Single track
Train speeds:	Track speed at trial location of 25mph (approx. 40kph)
Road / rail volumes:	Low density rail line, minimal vehicular traffic.
Target cost:	Approx. $ 65,000.00 USD (Roop et al., 2005)
Reliability	
Target rate of dangerous failure of protection system:	Unknown
Fail-to-safe capability:	In theory. Significant reliability issues. Missed train detection results in wrong-side failure.
State of warning provided to train driver:	No
Remote diagnostics:	None
Technical Characteristics	
Train detection:	6 magnetometers on each approach and a set of infrared detectors mounted on the steel posts at the crossing to confirm train presence.
Connectivity:	Cable
Warning activation time:	Unknown
Warning release time:	Unknown
Warning	
Active warning type:	Warning consists of a flashing LED array in an “X” pattern and a train directional advisor above the crossbuck of six yellow halogen lights sequentially activated to indicate the direction of approach. (Figure 1h)
Failure mode warning:	Same as train approach warning

3.7. ISIS-EK (Austria)

The ISIS-EK (Intelligentes System zur Identifikation und Signalisierung an nicht-technisch gesicherten Eisenbahnkreuzungen - intelligent system for identification and signaling of passive crossings) is an active advanced warning system (AAWS) using low-power LED variable message signs and lane lights to warn road users that they are in the proximity of a level crossing (EBE Solutions, 2008). Both road and rail vehicles are detected by track and road-side sensors, enabling the display of the traffic sign and lane lights. If the warning is activated by road-side sensors, the traffic sign and lane lights are deactivated after a delay. If the warning is activated by rail-side sensors, the traffic sign and lane lights are deactivated by detectors in range of the crossing. The system is solar powered, providing autonomy from the power grid.

Studies on the effect of the ISIS-EK warning system demonstrate a reduction of the average approach speed by 4kph (from 31 to 27kph), which they claim is due to increased attention of road users to the variable message signs (Kuratorium für Verkehrssicherheit, 2008). This project is a collaboration between Swarco Europe, ÖBB Infrastruktur Betrieb AG, Rail Cargo Austria, Kuratorium für Verkehrssicherheit (Austrian Road Safety Board), EBE Electrical Engineering GmbH and the University of Applied Sciences FH Joanneum, Kapfenburg (EBE Solutions, 2008).

Table 10 summarizes the characteristics of the ISIS-EK advanced warning system.

Table 10. ISIS-EK Advance Warning Device

Target Operating Environment	
Crossing type:	Single track
Train speeds:	$V_{max} \leq$ 60kph for trial site
Road / rail volumes:	Average 47 trains / day for trial site
Target cost:	€ 15.000 (€ 25.000 with lane lights)
Reliability	
Target rate of dangerous failure of protection system:	Not defined.
Fail-to-safe capability:	Unknown
State of warning provided to train driver:	No
Remote diagnostics:	Yes. Remote logging of status to central system and automatic transmission of alarm messages.
Technical Characteristics	
Train detection:	Infrared and radar sensors
Connectivity:	Wireless – data radio modem and Bluetooth. Encryption of data messages to prevent tampering.

Warning activation time:	Unknown
Warning release time:	Unknown
Warning	
Active warning type:	LED variable message sign 50m before the crossing with the danger sign “crossing without boom gates” and the text “in 50m” and flashing yellow lane lights. (Figure 1i)
Failure mode warning:	Unknown

3.8. LCLCWD Summary

Table 11 summarizes the LCLCWDs presented in the preceding sections. Warning types have been summarized as traffic lights (TrafficL), flashing lights (FlashL) and active advanced warning signs (AAWS).

Table 11. LCLCWD Summary

LCLCWD	**MICRO**	**SAL0**	**HRI-2000**	**HiLux**	**O’Conner**	**EVA 3000**	**ISIS-EK**
Country:	Switzerland	France	USA	Australia	USA	USA	Austria
Operating Environment							
Max # tracks:	1	1	1	1	1	1	1
Max train speeds:	100kph	100kph	-	80kph	80kph	-	60kph
Road / rail volume:	≤ 2 equiv. persons / hour	-	-	≤ 6 trains / day	-	(approx. 40kph during trial)	(avg. 47 / day during trial)
Target cost:	€ 55.000	€ 15.000	$ 15,000	$ 50,000	$ 100,000	$ 65,000	€ 15.000 (€ 25.000 with lane lights)
Actual cost:	-	-	$ 40,000	-	(exceeded target)	-	
Reliability							
Target rate of dangerous failure:	SIL3	≤ 1 miss over 106 operation cycles	-	SIL1	-	-	-
Fail-to-safe:	Yes	Yes	Yes	Yes	-	-	-
Warning							
Warning type:	TrafficL	FlashL	FlashL	FlashL / AAWS	-	FlashL	AAWS

4. Discussion

Of the systems reviewed in the preceding section, only the HRI-2000 and HiLux had publically available reliability data relating to trials that had been conducted. Figure 2 and 3 illustrate the reliability of the systems observed during the trials, and the proportion of correct operation to various failure conditions.

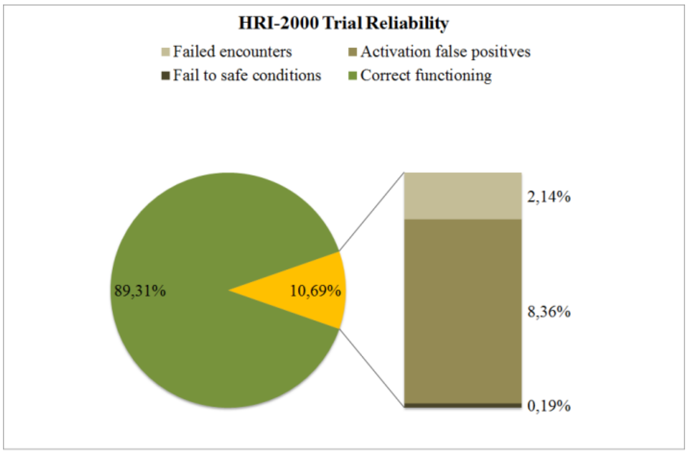

Figure 2. HRI-2000 trial reliability

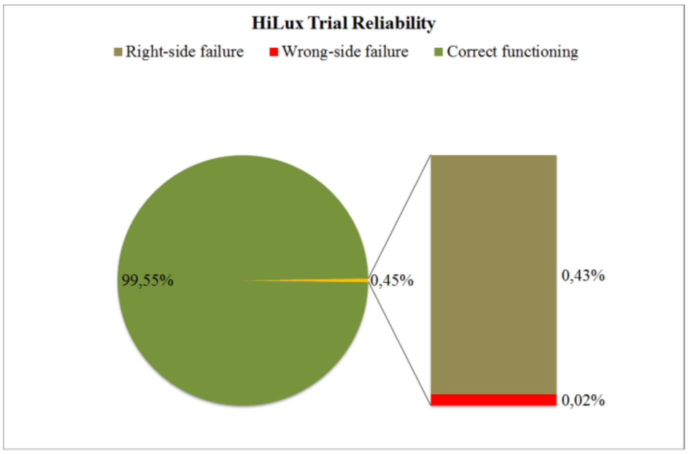

Figure 3. HiLux trial reliability

While the HRI-2000 trial had a failure rate of 10.69%, these failures were not considered to be wrong-side, as on these occasions, the train driver was notified of the failure state of the crossing protection system. The risk to road users was mitigated my implementing railway operation rules requiring the responsibility of failure to be assumed by the railway, and consequently requiring the manual flagging of crossings. Had the operational rules not required the train to stop and manually flag the crossing, the failure would have been considered as wrong-side. Failed encounters are in effect wrong-side failures mitigated by external risk reduction measures, i.e. the change of operation rules.

The HiLux system had a lower overall failure rate of 0.45%, however one of these failures was an unexplainable wrong-side failure. The acceptable rate of dangerous failure that can be tolerated should be determined through risk assessment. In the case of the HiLux LCLCWD with active advanced warning signs (AAWS) installed between 50-100 meters from a crossing, the crossing remains passive and the stop sign continues to be the predominant control. This approach potentially limits the legal consequences associated with having the warning present at the crossing, however, the safety benefit per dollar would have to be demonstrated to be greater than that of a conventional active protection system.

To quantify the safety benefit, road user behavior at passive crossings with AAWS' installed would have to be studied to determine to what extent they can improve safety. The following subsections discuss human factors issues of AAWS' and reliability issues associated with the use of alternative train detection technologies.

4.1. Human factors aspects of active advanced warning signs

A study conducted by ARRB Group Ltd. for VicRoads on behalf of the Victorian Railway Crossing Safety Steering Committee (VRCSSC) (Green, 2010) was unable to conclude if AAWS' influenced driver approach speeds to a level crossing. The trial involved the before and after evaluation of traffic and crossing activation data over a period of four weeks. The AAWS' were installed 130 meters before the active level crossing on approach.

Based on the small sample size, the study suggested that the AAWS' did not have an impact on the number or timing of violations. The report concludes that a larger sample would be needed for many rural level crossing locations if the results are to be provided with any confidence, as the sample size (traffic and trains) was not statistically significant.

It is suggested that the greatest benefit of AAWS' is for scenarios where there is poor sighting distance, or in providing further warning to drivers who are complacent or not fully alert when approaching the crossing.

Another human factors aspect of LCLCWDs is the effect of reliability on road user behavior. In 2009 the American Federal Railway Administration (FRA) sponsored the John A. Volpe National Transportation Systems Centre to conduct studies to examine the effects of active warning reliability on motorist behavior at conventional rail level crossings (Gil et al., 2009). Two experiments were conducted to examine the effects of false positives and false negatives on motorist behavior (i.e. activation of the warning when no train is approaching and missed train detection). Based on the results of both experiments, the study concluded that improving motorists' perception of signal reliability may improve compliance.

These studies were conducted using the American design of active level crossing warning consisting of two flashing red lights, where the safe failure mode of the level crossing is expressed in the same way as the train approach warning. Australia has traditionally followed American railway standards and uses this type of warning for conventional level crossings.

A number of the LCLCWDs described in the preceding section have specific expressions of failure. As railway operation rules for passive level crossings could apply to crossings treated with LCLCWDs, failure of the level crossing would have to be effectively communicated to the road user if they going to be required to take responsibility for train detection in the degraded mode. By installing AAWS' rather than an active warning at the level crossing, a specific expression of failure may not be needed, as the level crossing rules remain that of a passive level crossing, where the predominant control is a stop or give-way sign.

In 2009 research was conducted by Monash University Accident Research Centre (MUARC) to examine driver behavior associated with the use of various active warnings applied to passive level crossings (Lenné et al., 2009). The studies investigated the difference in driver behavior between crossings fitted with traffic lights and conventional red flashing lights as well as boom gates and conventional red flashing lights. A driving simulator was used to evaluate the driving behavior of 50 participants on four level crossing scenarios.

The road user behavior of failure mode of both conventional flashing red light and traffic light controls in failure mode were evaluated, however, project stakeholders decided to express failure as a steady read light on the traffic lights, rather than the standard flashing amber (the same signal for an approaching train) in order to be consistent with the conventional warning. As such, negligible difference was seen in driver behavior between the failure mode of the conventional warning and the traffic lights. In both cases a significant proportion of the drivers waited for up to four minutes before driving through the crossing.
Further research is needed to determine the effectiveness of different expressions of failure on road user behavior.

4.2. Reliability issues of alternative train detection technologies

Most of the LCLCWDs that have been trialed rely on the use of alternative technology for train detection equipment installed on the railway. Such systems significantly deviate from conventional operation and design and can often be very complex (e.g. GPS activation). The failure modes for such technologies are not easily understood and the effort in demonstrating that these technologies are safe and reliable is likely to outweigh the cost savings that can be gained through the adoption of LCLCWDs, especially given that there is no coherent type approval processes in Australia.
Attempts have been made to investigate LCLCWDs that are not installed on the railway, as such systems are not likely to be constrained by railway liability issues.
Hellman (Hellman and Ngamdung, 2010) describes the research conducted by the Texas Transport Institute in 2006 to determine if train detection technologies installed off-railway could be sufficiently reliable. Radar and acoustic detection systems were tested at a level crossing in Texas in shadow-mode, comparing the performance of these sensors with the existing track-circuit train detection system. The equipment for both systems were mounted on a traffic light utility pole at a distance of 6 meters from the railway and at a height of about 4 meters.
Data was collected for approximately 1500 activations over 76 days from August 2006. While 100% of trains were detected by the sensors, high false train detection rates were observed (57% for the radar system and 94% for the acoustic system) due to issues of the sensors differentiating between rail and road traffic. As such, the systems were not considered reliable enough to satisfy railway reliability concerns, even though the system was not installed on the railway.
Hellman (Hellman and Ngamdung, 2010) reviews a number of trials in the U.S.A and concludes that the most promising non-track circuit-based technologies are based on GPS and magnetic flux. He further notes that while train-centric systems (e.g. GPS) eliminate the need to install track-side equipment, designers of the HRI-2000 system were unable to satisfy the fail-safe operation requirement of the Federal Railroad Administration (FRA) crossing grade regulation.
Rail level crossing activation systems based on Global Navigation Satellite Systems[4] (GNSS) can provide significant opportunity for cost reduction and improvement of safety for Australia in the long term.
There are currently efforts underway to develop an Australia-wide Train Protection and Control (TPC) system. This system, the Advanced Train Management System (ATMS), aims to replace trackside signaling, provide precise train position information, provide enforcement of authorities on each locomotive and provide digital control centers with the capability to control all traffic on the ARTC national network (Groves, 2010).
A core part of ATMS Train-borne System is the Location Determination System (LDS). The LDS determines the position of locomotives with sufficient accuracy to identify the track and clearance of points using a combination of GPS and an inertial navigation system. The Train-borne System constantly updates the current location to determine applicable speed limits and the distance to the end of authority. ATMS tracks trains by means of location reports received from the on-board system and occupancy reports received from Track-side Interface Units (TIUs) monitoring Track Circuits (Donoghue, 2010).
Leveraging such infrastructure for automated level crossing activation could prove to be an efficient and cost-effective way to increase safety at level crossings, given that the LDS is a vital system and will need be developed to safety levels suitable for TPC. A number of issues that will need to be considered for both TPC and automatic level crossing activation include safety issues of GNSS including provisioning of GNSS integrity data and interoperability issues relating to the use of the LDS and of trains not equipped with an LDS.

5. A Consistent Approach for Evaluation

In order to find a way forward for the adoption of LCLCWDs in Australia, it is necessary to first identify safety goals and targets, which will be used to determine appropriate safety integrity and availability requirements.
The reliability and Tolerable Hazard Rate (THR) of crossing protection systems has to be determined with appropriate risk management processes to ensure that the risk wrong-side failure can contribute towards a fatality is consistent with “So Far As Is Reasonably Practicable” (SFAIRP) principles, i.e. that everything practicable is done to reduce the risk, that the risk is reduced to a tolerable level, and that additional control measures are shown to have been grossly disproportionate to the risk reduction associated with the implementation of the additional control.
A cost-benefit analysis of LCLCWDs that meet these requirements will determine the effectiveness of such systems over conventional level crossing warning systems, and whether a network-based approach to increasing safety utilizing a combination of conventional and low-cost interventions can produce better outcomes for Australia than the current approach of incrementally upgrading level crossings with conventional interventions. Research into the effectiveness of the AAWS’ and expressions of failure is needed to provide data that can be used as part of the risk assessment process.

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[4] The Global Navigation Satellite System (GNSS) is the global term for satellite navigation systems that provide global coverage including constellations such as the Global Positioning System (GPS), Galileo, and GLONASS.

As there are a number of different level crossing scenarios and configurations, three general classes of LCLCWDs have been identified from those reviewed to facilitate the development of better focused evaluation criteria and safety requirements. The following subsections detail three classes of LCLCWD.

5.1. Class 1 LCLCWD

This class of LCLCWD (Figure 4) is comprised of a train detection system with a mechanism for activation and deactivation, a control system and a pair of active advanced warning signs (AAWS) between 50-200 meters before (on approach of) a passive level crossing. The rail level crossing itself is not treated and remains passive, with the predominant control being a stop or give-way sign. Railway operation rules are unchanged, and continue to be those of a passive level crossing.
This type of intervention is least likely to have significant legal obstacles, although the effectiveness of AAWS' has still to be proven given the results of prior research discussed in the preceding section.

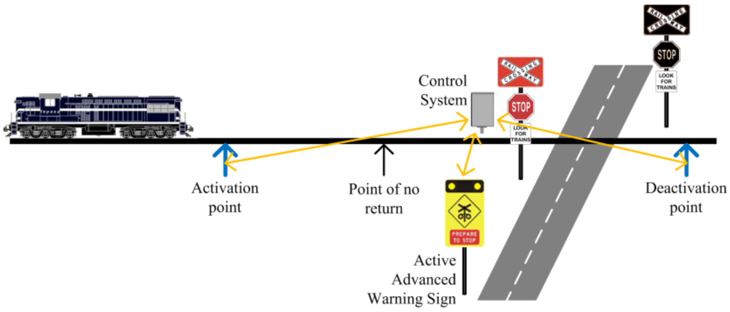

Figure 4. Class 1 LCLCWD (Passive Crossing with AAWS')

5.2. Class 2 LCLCWD

This class of LCLCWD (Figure 5) is comprised of a train detection system with a mechanism for activation and deactivation, a control system and a pair of active warning signs installed at the crossing. As the rail level crossing itself is treated, it effectively becomes an active crossing. This type of intervention does not have a monitoring point, therefore the train is unaware of a potential failure of the LCLCWD. The reliability requirements for this type of LCLCWD are likely to be more stringent that the class 1 device. Train detection technologies insofar as practicable, should be designed with fail-safe principles, as missed train detection results in wrong-side failure. Railway operation rules are expected to be unchanged, and continue to be those of a passive level crossing. This requires road users to take responsibility in the case of a failure.
The legal implications of this type of crossing are complex, and would require legislative reform unless it can be demonstrated through good practice risk assessment that the risk has been reduced "so far as is reasonably practicable". Additional measures such as the differentiation of LCLCWD warning signs from conventional ones and road-user education may be effective at reducing risk.

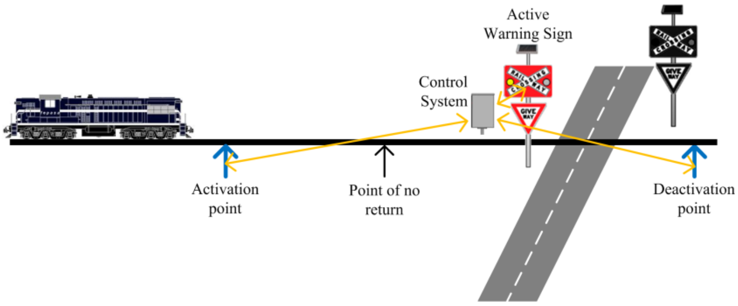

Figure 5. Class 2 LCLCWD (Active Crossing)

5.3. Class 3 LCLCWD

This class of LCLCWD is comprised of a train detection system with a mechanism for activation and deactivation, a control system, a pair of active warning signs installed at the crossing and a monitoring mechanism that communicates the protection state of the crossing to the train. Unlike the class 2 LCLCWD, if there is a train detection failure, the system does not fail wrong-side. An external risk reduction measure is used, such that if a level crossing is not protected, the train driver becomes aware and reduces speed or comes to a complete stop at the approach of the crossing in order to manually flag the crossing.
This intervention requires the change of railway operation rules for the crossing, as the railway in this case takes responsibility in the case of a failure. This change of operation rules can have a negative impact on the railway performance if the system is not reliable. A cost-benefit analysis would be required to determine if the cost of LCLCWDs and the potential losses due to reliability issues is disproportionate to that of high-reliability conventional systems.

Figure 6 and 7 illustrate two sub classes representing a track-side versus train-borne approach. The class 3B utilizes GNSS for train localization and remote activation of the level crossing. Remote activation has the advantage over fixed train detection sensors of supporting flexible train approach speeds.
Although there are similar legal issues to the class 2 LCLCWD, the safety argument may be assisted by the fact that GNSS is becoming an accepted technology in railway for many applications including Train Protection and Control (TPC).

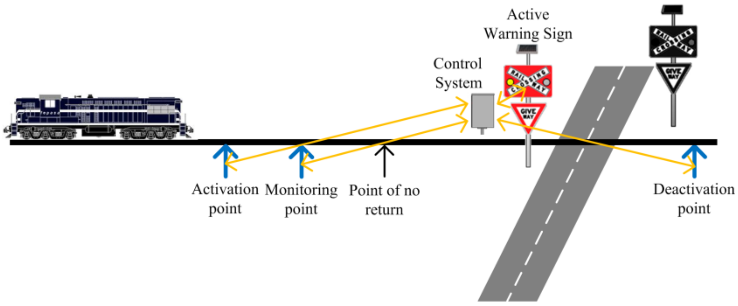

Figure 6. Class 3A LCLCWD (Active Crossing with Monitoring)

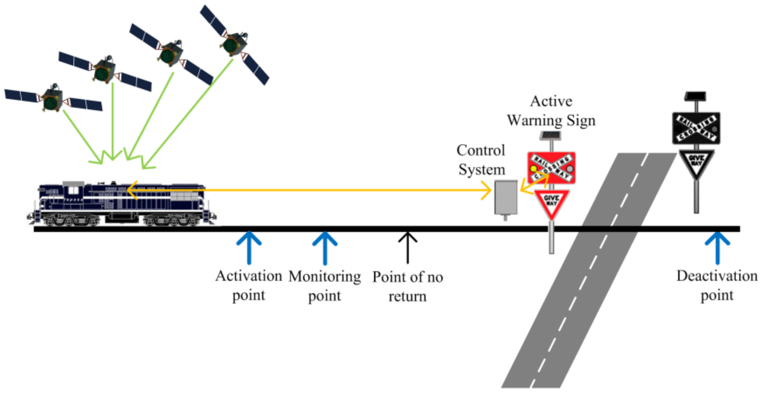

Figure 7. Class 3B LCLCWD (Active Crossing with Monitoring)

6. Conclusion

This paper has discussed major obstacles for the adoption of LCLCWDs in Australia including legal and reliability issues. A review of LCLCWD trials in Australia and internationally was presented, illustrating different approaches to LCLCWD technology and management of legal issues.
The Cooperative Research Centre (CRC) for Rail Innovation aims to develop safety requirements and to facilitate the collection of availability and other operational data through homologation testing of a range of candidate LCLCWDs. The study of expressions of failure on road user behavior is planned as part of the second stage of the affordable level crossings project.
The following research, analysis and testing activities are part of a strategy that could significantly contribute towards answering the cost-benefit and reliability questions of LCLCWDs:

- The definition of reliability targets for low-cost rail level crossing devices consistent with SFAIRP principles;
- Long-term testing of low-cost rail level crossing technology in a real-world environment to prove availability aspects and obtain operational history;
- In-depth cost-benefit analysis including the evaluation of whole lifecycle costs (ongoing maintenance etc.) and the costs of failure on rail and road traffic in terms of delay (lost profit, scheduling issues, etc.) and potential costs arising from litigation in the case of an incident;
- Investigation of new approaches to reliability and fail-safety using new technologies, protocols, etc. for the next generation of LCLCWD technology;
- Investigation of the human effects of failure on road safety, in particular the indication of failure to the road user and the effects of false positives and negatives; and
- If LCLCWDs can be demonstrated to satisfy safety targets whilst providing a significant cost-benefit, investigation of required legislation to support the use of low-cost level crossing technology should be supported. It is assumed that this technology will be differentiated from conventional level crossing technology and their use restricted to regional level crossings with the understanding that the technology will not be as available as conventional technology. Such legislation should address the tort liability issues that make it currently negligent to install low-cost level crossing technology.

7. Acknowledgment

We gratefully acknowledge the Victorian Department of Transport, the Australian Rail Industry Safety and Standards Board (RISSB) and VicTrack for their support in providing valuable information and insight into LCLCWD issues. We are also grateful to the CRC for Rail Innovation (established and supported under the Australian Government's Cooperative Research Centres program) for the funding of this research. Project No. R3.111/Dz6.

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