Low Cost Railway Level Crossings

Christian Wullems

Ph.D., B.IT (Hons), MACS CP, MIEEE

Cooperative Research Centre for Rail Innovation and Centre for Accident Research and Road Safety – Queensland, Queensland University of Technology

SUMMARY

The Cooperative Research Centre (CRC) for Rail Innovation is conducting a tranche of industry-led research projects looking into safer rail level crossings. This paper will provide an overview of the Affordable Level Crossings project, a project that is performing research in both engineering and human factors aspects of low-cost level crossing warning devices (LCLCWDs), and is facilitating a comparative trial of these devices over a period of 12 months in several jurisdictions.

Low-cost level crossing warning devices (LCLCWDs) are characterised by the use of alternative technologies for high cost components including train detection and connectivity (e.g. radar, acoustic, magnetic induction train detection systems and wireless connectivity replacing traditional track circuits and wiring). These devices often make use of solar power where mains power is not available, and aim to make substantial savings in lifecycle costs.

The project involves trialling low-cost level crossing warning devices in shadow-mode, where devices are installed without the road-user interface at a number of existing level crossing sites that are already equipped with conventional active warning systems.

It may be possible that the deployment of lower-cost devices can provide a significantly larger safety benefit over the network than a deployment of expensive conventional devices, as the lower cost would allow more passive level crossing sites to be upgraded with the same capital investment.

The project will investigate reliability and safety integrity issues of the low-cost devices, as well as evaluate lifecycle costs and investigate human factors issues related to warning reliability. This paper will focus on the requirements and safety issues of LCLCWDs, and will provide an overview of the Rail CRC projects.

INTRODUCTION

In the 10-year period from 2000 to 2009, there have been 248 collisions and 35 fatalities at public level crossings with passive controls in Australia [1]. A stocktake undertaken by the Australian Railway Industry Standards and Safety Board (RISSB) in 2009 [2] indicates that there are 8,838 public level crossings in Australia, of which 67% are protected with passive controls (i.e. stop or give-way signs). Although the risk at a single level crossing is relatively low, collectively level crossings with passive controls represent a significant safety concern for Australia, as there is the potential for collisions with high consequences.

The cost of installing active protection at all of these crossings has been estimated by Cairney [3] in 2003 as being between $1.2 billion and $1.8 billion, excluding maintenance and other lifecycle costs. The adoption of lower-cost solutions has therefore been a focus of Australian railways in recent years as a potential solution for improving safety at the multitude of level crossings with passive controls.

Low-cost level crossing warning devices (LCLCWDs) are typically characterized by the use of alternative technologies for train detection, connectivity and power supply, with the objective of reducing equipment, installation, maintenance and operating costs. Installation costs of LCLCWDS are expected be less than 25% of the installation cost of conventional level crossing warning devices.

This paper discusses challenges in the deployment of low-cost level crossings in a regional Australian context, opportunities for cost reduction based on the cost profile of conventional level crossings, safety of low-cost level crossings and the tranche of Rail CRC projects that are addressing these challenges.

1. Deployment of Low Cost Level Crossings in Regional Australian

The majority of Australia's public level crossings with passive controls (i.e. stop or give-way signs) are found in remote areas with low population density. The contexts of these level crossings range from seasonal lines (e.g. for transport of grain) and lines with low volumes of rail traffic (e.g. less than 1 service a week) to coal lines with frequent services.

These contexts often bring with them a number of challenges:

- *Mains power is not always available*. Solar power is a common alternative, however, driving boom gates with solar power may not always be achievable at a reasonable cost if there is insufficient solar yield.
- *Traditional track circuit based train detection can be unreliable in an environment where trains are infrequent.* Prolonged or intermittent failures can occur due to oxidation of the rail surface. Even lightly rusted rails when dry can cause problems, especially when there are prolonged periods without trains [4]. Other environmental factors affecting track circuit integrity include leaf residue, oil film, coal dust, sand and crushed ballast [4]. Axle counters are often used instead of track circuits in these environments; however, axle counters can be damaged during maintenance activities [5]. There are also issues relating to reset and restoration procedures that need to be taken into account.
- *Harsh environmental conditions*. Climatic conditions in Australia vary depending on region and proximity to the coast. Temperatures generally can range from −10°C to +55°C. In-land regions are characterized by high dust levels and low humidity, whereas coastal areas are exposed to high levels of salinity and possible cyclone conditions. Rainfall can vary significantly; however, it is not unusual to have several hundred millimetres of rainfall within a 24-hour period.
- *Remote locations can result in lengthy response and repair times*. Remote monitoring can improve the response time for detectable failures and fault conditions, and is significantly more effective than relying solely on scheduled inspections by maintenance staff. It is expected that remote monitoring will be a key functionality of LCLCWDs.
- *GSM/GPRS coverage may be limited for remote monitoring*. Where GSM in unavailable, there are alternatives including Iridium (satellite-based communications) that can be used to facilitate monitoring, albeit at a higher cost.

The following key principles have been defined by the Rail CRC Affordable Level Crossing project team for the deployment and operation of LCLCWDs as a primary control on low-exposure level crossings:

- LCLCWDs are not a replacement or substitute for existing high-integrity level crossing warning devices.
- LCLCWDs are intended for deployment at low exposure level crossings with passive controls (e.g. single track lines with little or no passenger traffic, low train volumes and low road vehicle volumes). It is also assumed that single bi-directional track is not within 25 seconds of duplicated track. Level crossings with a siding are excluded on the basis that a different methodology for activating protection is likely to be required.
- Definition of exposure should be based on risk evaluation. This principle should be consistent nationally, however, individual accredited railway operators (AROs) can make the decision to define more stringent requirements (e.g. no passenger trains, reduced speed).
- The interface to the road user is the RX5 flashing light assembly (AS1742.7 [6]), such that there are no expected regulatory changes to road rules. This does not, however, preclude the use of other road user interfaces at a later stage should there be evidence in support of a different interface. The residual risk associated with a potential failure must be mitigated by other controls on the hierarchy. Such controls include educating motorists of the system of interventions used; their effect and limitations; signage warning motorists of the potential for failure; and additional passive interventions.
- The safety integrity of LCLCWDs should be at least commensurate with risk at low exposure crossings.
- The installation and lifecycle costs of LCLCWDs must be sufficiently low to demonstrate a benefit-cost ratio better than that of conventional systems for treatment of a population of low-exposure level crossings with passive controls for a given investment. The Rail Safety Act requires AROs to eliminate risks, and where this is not practicable, to reduce those risks so far as is reasonably practicable. In determining what is reasonably practicable, the benefit of risk

reduction including societal benefits such as mitigated safety loss are weighed against the cost of implementing the control.

Regarding Australian rail safety legislation, on the 4th November 2011 Australia's transport ministers approved the new Rail Safety National Law [7], which will commence in 2013. The Law replaces existing state and territory rail safety legislative schemes with a national scheme and will establish a single rail safety regulator. Australian states have also recently made the transition to the model Work Health and Safety Bill 2011 [8], harmonising health and safety laws across Australia. The new Rail Safety National Law explains the relationship and its operation with the OHS legislation and circumstances in which both apply.

2. Opportunities for Cost Reduction

Equipment costs have often been the sole focus of efforts to develop a low-cost level crossing solution. While equipment cost is important, it represents a relatively small portion of installation and lifecycle costs.

Hellman and daSIlva [9] summarize an analysis of baseline grade crossing system costs published by the American Railway Engineering and Maintenance-of-Way Association (AREMA). Approximately 49% of the estimated costs are related to equipment. The remaining 51% are related to installation, engineering and site survey, ground materials and freight. Other than reducing equipment costs, there is significant opportunity for cost reduction in the installation and commissioning activities that can be facilitated through alternative design or streamlining of existing processes. The following subsections detail opportunities for cost reduction in installation, operation and maintenance of the product.

2.1. Installation costs

Wayth [10] provides a cost analysis for implementation of level crossings with boom barriers in Victoria, identifying options for cost reduction. Table 1 summarizes the items where cost reduction can be influenced by the design of the LCLCWD.

	Conventional LX costs	Opportunity for cost reduction
Energy supply	Provision of mains power (including trenching)	Use of solar power
Component connectivity	Trenching for cable runs	Use of wireless communications
Train detection	Track improvement work for track circuits and grade crossing predictors (e.g. head bonding, ballast cleaning, provision of insulating rail joints, etc.);	Use of alternative train detection systems not requiring track work

Table 1. Installation costs

Track circuits and grade crossing predictors are among train detection technologies commonly used in conventional level crossing in Australia. Both these technologies require track work, significantly increasing the cost of installation.

Reliability of train detection is a key issue and one of the potential causes of a wrong-side failure of a level crossing, i.e. if a train detection system fails to detect an approaching train (failure to shunt).

Train detection technologies dependant on wheel to rail conductivity are notoriously unreliable after lengthy periods with no rail traffic. Conventional approaches in this context may prove to be costly with re-commissioning costs and high levels of maintenance required to ensure reliable train detection. Poor shunting conditions also affect grade crossing predictors, potentially resulting in reduced warning times [11].

The motivation behind the use of alternative train detection technologies is not only to reduce the equipment and installation costs, but also to ensure maintenance and other lifecycle costs are lower than their conventional counterparts.

Alternatives to wheel to rail conductivity based train detection include axle counters, which are already type approved and used in many Australian railways.

In an attempt to further reduce costs, several low cost train detection technologies have emerged in trials and products around the world. A non-exhaustive list of technologies is provided below. Note that reliability issues appear to be a significant stumbling block for many of these.

- Radar;
- Acoustic sensors;
- Magnetic anomaly;
- Magnetic induction; and
- GPS activation.

A number of emerging LCLCWDs are based on technologies such as radar and have been designed to operate and detect trains from outside of the danger zone (i.e. the train detector is not installed within 3 meters of the danger zone). Installation costs related to safeworking can therefore be significantly reduced, resulting in a lower installation cost.

Other costs such as design, drafting, testing and commissioning work can potentially be streamlined for a cross-section of level crossings that are similar in terms of exposure, sighting distance, etc. This is what is commonly termed as the "crossing in a box" concept. These efficiencies, however, can be best achieved by railway companies.

2.2. Operational costs

LCLCWD design can also influence operational costs as illustrated in the items detailed in Table 2. Note that some operational costs such as communication for remote monitoring are expected to be at least equivalent to that of conventional level crossings, if not more costly due to GSM coverage issues in some areas.

	Conventional LX costs	**Opportunity for cost reduction**
Train detection	On seasonal lines with train detection dependant on wheel to rail conductivity, re-commissioning is required after extended periods without trains	Use of alternate train detection systems that reliably detect trains after significant periods of inactivity
Power supply	Mains power supply (supply costs)	User of solar power

Table 2. Operational costs

2.3. Maintenance and other lifecycle costs

The design of a LCLCWD can strongly influence the total cost of ownership. For example, components that do not require continuous adjustment or maintenance and have a modular design facilitating a short time to repair are likely to provide significant savings over the lifetime of the warning device. Remote monitoring and the provisioning of on-site diagnostic tools can also significantly improve time to repair, and hence costs over the lifetime of the device.

Costs related to safeworking for maintenance can also be reduced if level crossing equipment that requires regular maintenance is installed 3 meters from the rail corridor.

Lifecycle evaluation criteria are being developed as part of the Rail CRC Affordable level crossing project to provide a basis for comparison of warning devices, which otherwise would be difficult to evaluate.

3. Safety of Low Cost Level Crossings

One of the key challenges for developers of LCLCWDs is to reduce costs whilst maintaining a high level of safety integrity.

The use of alternative power supplies, connectivity and train detection systems to reduce costs and provide suitable train detection for the harsh environment in regional areas of Australia, can potentially result in increased complexity and present challenges to meeting safety targets (i.e. tolerable hazard rates). Section 3.2 provides examples of this and argues why it might be necessary to lower requirements of safety integrity.

Two of the safety principles stated earlier in the paper are (1) that the safety integrity of LCLCWDs should be at least commensurate with the risk at low exposure crossings; and (2) that the interface to the road user should be the RX5 flashing light assembly as defined in AS1742.7 [6].

By requiring LCLCWDs to have the same road user interface as conventional level crossing warning devices, the fundamental difference between low-cost and conventional systems is constrained to train detection, control of the warning (i.e. level crossing logic controller) and the energy supply system.

Level crossings are not in themselves fail-safe, as they rely on procedures to mitigate risks of failure. While individual components can be designed with a high level of safety integrity and reliability, the failure of the primary power supply requires human intervention for both detection of the condition and remediation. Otherwise, if the primary power supply fails, it is inevitable that the battery backup with eventually be exhausted and the crossing will fail wrong-side.

Remote monitoring of the crossing and time to repair are therefore critical in ensuring safety of the level crossing, especially for level crossings in remote areas of Australia.

The following subsections discuss one of the common processes for satisfying safety requirements and the impact cost reduction is likely to have on safety.

3.1. Demonstrating safety targets have been met – a high level overview

The following overview is based on the CENELEC railway standards EN50126 [12], EN50128 [13] and EN50129 [14].

Suppliers of LCLCWDs as part of an approval process would typically be required to provide a safety case containing evidence of quality management, safety management and functional and technical safety appropriate to the function of the LCLCWD.

Safety management evidence involves demonstrating compliance with all the elements of the safety management processes defined EN50126 [12].

A technical safety report (demonstrating functional and technical safety) provides evidence of safety analyses, design principles and technical principles that assure the safety of the design. The report should provide sections including assurance of correct functional operation; effects of faults; operation with external influences; safety-related application conditions and safety qualification tests.

As new and alternative level crossing warning devices are typically comprised of programmable electronic devices (i.e. programmable logic controllers), safety process evidence becomes more important in providing assurance systematic failures have been adequately addressed. IEC61508 [15] is an international standard for functional safety of electronic and programmable electronic safety related systems. Railway specific versions of this standard have been developed in CENELEC EN50128 [13] and EN50129 [14].

EN50129 [14] describes the process of safety acceptance and approval; and provides an annex describing the derivation, allocation and implementation of safety requirements for safety-related systems for railway application consistent with IEC61508 [15].

According to the processes defined in this document, railways would typically be responsible for the following activities:

- Definition of the system in a generic, technology independent way;
- Identification of hazards relevant to the system and estimation of hazard rates;
- Analysis of potential consequences; and
- Definition of risk tolerability criteria and tolerable hazard rates (THR) for identified hazards by estimating the resulting individual risk or deriving THRs from a comparison with the performance of existing systems using statistical or analytical methods.

A supplier of a level crossing warning device would be typically required to demonstrate that hazards have been adequately controlled and that the device meets the associated safety targets for each of the hazards.

Two types of failure integrity need to be considered in demonstrating that safety targets are met: random failure (i.e. failures due to physical causes and a variety of degradation mechanisms) and systematic failure (i.e. failures due to flaws in the system, where systems fail consistently when subjected to the same conditions). The THR is used to justify systematic and random failure integrity requirements.

Assuming the railway has defined THRs, Safety Integrity Levels (SILs) can be allocated to sub-systems based on the THRs.

SILs are specified as one of four discrete levels, where the apportioned THR per hour falls within a range associated with a given level. While random failures can be quantified using probabilistic calculations, this is not possible for systematic failures, and therefore each safety integrity level is associated with a group of methods and tools used to provide the stated level of confidence [14].

The supplier would further apportion the failure rates and allocate SILs to equipment in the sub-systems implementing the safety function(s). Typical methods for facilitating apportionment include reliability block diagrams, fault trees, etc.

Refer to CENELEC railway standards EN50126 [12], EN50128 [13] and EN50129 [14] for more details on the above process and supporting methods.

3.2. Impact of cost reduction on safety

This section illustrates the impact cost reduction measures discussed in Section 2 can have on meeting safety targets. A non-exhaustive list of hazards identified with respect to the safety function "*to provide timely warning of an approaching train*" is detailed below:

- Warning not given for approaching train;
- Warning given with incorrect time delay for approaching train;
- Warning extinguished before train has left crossing;
- Warning not extinguished when train has left crossing; and
- Warning not extinguished with correct time delay when train has left crossing.

In the following example, the hazard "*warning not given for approaching train*" is used.

Figure 1 and Figure 2 are high-level fault-trees illustrating the difference between a flashing-lights-only conventional track-circuit based level crossing warning device and a LCLCWD with wireless communications and multiple power supplies.

The fault-trees illustrate that the cost-saving wireless communications has added significant complexity to the system and has resulted in more components that can contribute to the top-level dangerous failure rate. This could potentially result in equipment costs increasing substantially with respect to the conventional equipment in order to meet the THR.

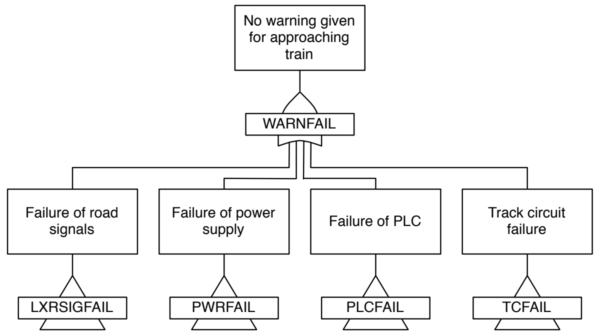

Figure 1. Fault tree – conventional

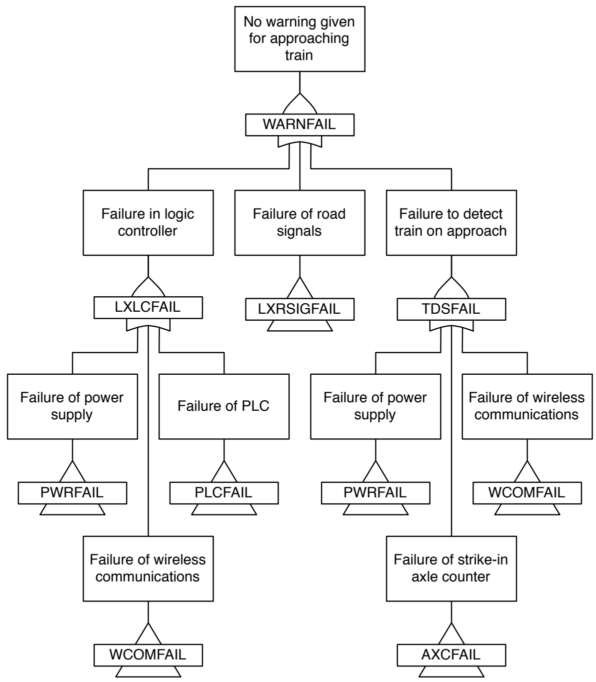

Figure 2. Fault tree for alternative (axle counter with wireless)

Given that one of the key principles for the adoption of LCLCWDs is that safety integrity is at least commensurate to the risk at low exposure crossings, a case could be made for reducing the THRs for a specific cross-section of low-exposure level crossings. This is perhaps the most significant hurdle in progressing the argument for support of LCLCWDs.

The Rail CRC Affordable Level Crossings project is conducting a risk assessment to determine whether hazard rates lower than the current performance of conventional level crossing warning devices are tolerable at low exposure level crossings. The risk assessment also aims to determine whether LCLCWDs that meet the lower THRs can collectively provide a better safety benefit for treatment of a population of level crossings than conventional warning devices for the same budget.

The lower safety requirements also have legal implications for the railway, including issues of Tort liability and compliance with the Rail Safety Act. Section 4.2 discusses the strategy for addressing these issues as part of the Rail CRC's tranche of projects investigating safer level crossings.

4. Rail CRC Projects

4.1. The affordable level crossings project

The CRC for Rail Innovation's Affordable Level Crossing project aims to facilitate a field trial of candidate LCLCWDs at several high-exposure and low-exposure sites. While this process is not a type approval, it is expected to collect data in a wide range of operating and environmental conditions over a period of 12 months, providing confidence that the candidate LCLCWDs are capable of performing as intended in the target contexts.

The trial will be conducted in shadow-mode, where systems to be tested will be installed in parallel to existing vital track circuits. The warning interfaces of the systems being tested will not be provided to road users. The trial aims to log data from both the vital systems and candidate LCLCWDs, facilitating the collection of comparative performance data without affecting the safety of the rail level crossing or vital signaling at trial sites.

In addition to the trial, the project is developing lifecycle evaluation criteria to support the selection of candidate systems, and the development of a risk assessment in support for lower safety targets.

Human factors issues related to failure of warnings at level crossings are also being investigated. The human factors research is investigating the effect of frequent and prolonged right-side failure on road user behaviour. It is expected that this research will inform reliability targets for LCLCWDs.

Gildersleeve and Wullems [16] discuss the human factors issues in more depth and outline the human factors research being conducted as part of the Rail CRC Affordable Level Crossings project.

4.2. Rail level crossing intervention framework project

The CRC for Rail Innovation's Level Crossing Intervention Framework project aims to progress the underlying argument for LCLCWDs with lower safety targets for a cross-section of low-exposure crossings.

The project involves the development of a position paper based on the risk assessment developed in the Affordable Level Crossings project. It is anticipated that the position paper and supporting arguments will be used to facilitate a stakeholder review and to seek independent advice and review from economists, legal experts and risk experts.

The legal advice is expected to explore whether the deployment of LCLCWDs on this basis follows the intent of the Rail Safety Act and the obligation of the AROs to reduce risk so far as is reasonably practicable (SFAIRP). Advice on the Tort liability issue will also be sought, addressing concerns where a collision occurs at level crossing with a LCLCWD, and it is found that the same collision would not have occurred with a conventional warning device.

Should there be a satisfactory outcome from the reviews and advice, it is anticipated that a decision-making framework will be developed with a series of detailed case studies to support the decision making process.

The CRC for Rail Innovation does not advocate the use of less than fail-safe interventions in a manner inconsistent with the duty of care obligations.

CONCLUSIONS

This paper has presented a discussion of issues relating to the deployment low-cost level crossing warning devices (LCLCWDs) in regional Australia. The paper described the deployment context and identified challenges relating to harsh Australian conditions and reliability of train detection on seasonal lines.

Opportunities for cost reduction influenced by the design of LCLCWDs were presented, and a high-level overview of the process for demonstrating functional and technical safety was given. This set the scene for a discussion on the impact of cost reduction on safety and the possibility of reduced safety targets for LCLCWDs.

The paper concluded with an overview of the Rail CRC projects that are addressing the issues discussed in this paper.

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REFERENCES

1. Independent Transport Safety Regulator (ITSR). Level crossing accidents in Australia. Transport Safety Bulletin [serial on the Internet]. 2011: Available from: http://www.transportregulator.nsw.gov.au/rail/publications/transport-safety-bulletins/level-crossing-accidents-in-australia/view.
2. Railway Industry Safety and Standards Board. Level Crossing Stocktake. 2009.
3. Cairney P. Prospects for improving the conspicuity of trains at passive railway crossings: Australian Transport Safety Bureau. 2003 Contract No.: CR217.
4. Railway Group Approved Code of Practice. General Information on Track Circuits. London, UK Safety & Standards Directorate, Railtrack PLC; 1998.
5. Railway Group Approved Code of Practice. Introduction and Use of Axle Counters - Managing the Risk. London, UK Safety & Standards Directorate, Railtrack PLC; 2003.
6. Standards Australia. AS1742.7-2007 Manual of uniform traffic control devices Part 7: Railway crossings. 2007.
7. National Transport Commision Australia. Rail Safety National Law. Standing Commitee on Infrastructure and Transport; 2011.
8. Safe Work Australia. Model Work Health and Safety Bill 2011.
9. Hellman A, daSilva M. Low-cost Warning Device Industry Assessment: U.S. Department of Transportation Federal Railroad Administration 2011.
10. Wayth R. Preparation of a Requirements Document for a Low Cost Level Crossing Warning System in Victoria (Discussion Document v0.1). Melbourne VicTrack Access 2011.
11. Rail Safety and Standards Board. Minimising service disruption from failures of track circuit actuators (assisters) - TCA Risk Model Trial: Level crossing predictors train detection performance. 2009
12. CENELEC - European Committee for Electrotechnical Standardization. EN50126 Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS). 2006.
13. CENELEC - European Committee for Electrotechnical Standardization. EN50128 Railway applications - Communication, signalling and processing systems: Software for railway control and protection system. 2001.
14. CENELEC - European Committee for Electrotechnical Standardization. 50129:2003 Railway applications - Communication, signalling and processing systems: Safety related electronic systems for signalling. 2003.
15. IEC - International Electrotechnical Commission. 61508: Functional safety of electrical/electronic/programmable electronic safety-related systems. 2010.
16. Gildersleeve M, Wullems C. A human factors investigation into the unavailability of active warnings at railway level crossings. ASME/IEEE 2012 Joint Rail Conference: American Society of Mechanical Engineers; 2012.