A systems approach to reducing trauma at rail level crossings

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EXECUTIVE SUMMARY

The continued occurrence of rail level crossing (RLX) collisions across the world demonstrates that the longstanding problem is not being solved by current interventions. Current solutions to the problem, such as grade separation and installation of boom gates at all crossings provide considerable safety improvements but are cost-prohibitive. Therefore, new and innovative approaches to improving RLX design are required. This research program adopted such an approach to the analysis and re-design of RLXs based on systems theory with the overall aim of developing and evaluating new designs to improve safety at RLXs.

Research methodology

The research program involved the following four phases.

Phase 1: Collection of data regarding existing RLX system functioning
Novel data were collected on system functioning and user behaviour at both ‘active’ and ‘passive’ RLXs. A range of data collection activities were undertaken including on-road studies of driver behaviour when driving through RLXs, cognitive task analysis interviews with drivers, a diary study of road user behaviour at RLXs, subject matter expert interviews, documentation review and in-cab train rides.

Phase 2: Systems thinking analyses of behaviour in existing RLX environments
The data collected in Phase 1 were used to build models of the RLX system using cognitive work analysis (CWA). Furthermore, hierarchical task analysis (HTA) was applied to understand the ‘tasks’ undertaken by humans and technology at RLXs.

Phase 3: Development and initial refinement of prototype RLX design concepts
Insights were extracted from the systems analyses and used in participatory design workshops involving stakeholders from the road and rail industries. Initial concepts underwent desktop evaluation and were refined to address potential issues. The workshops, involving RLX stakeholders, produced four prototype designs. In addition, two design concepts were generated by the research team, resulting in a total of six design concepts for evaluation.

Phase 4: Formal evaluation of design concepts
The six design concepts were evaluated in driving simulator studies and through a survey study of road users (including drivers, cyclists, motorcyclists, pedestrians and heavy vehicle drivers).

Recommendations

Based on the findings from the research program, the following recommendations are made.

Recommendations for the introduction of in-vehicle warning devices
In general, the in-vehicle warning devices tested demonstrated considerable benefit and appeared to have acceptance from users. The following recommendations are made to support the appropriate introduction of intelligent transport system (ITS) technologies for improving RLX safety:

- That both speed management (e.g. the GPS average speed concept) and guidance on the field of safe travel (e.g. the Intelligent level crossing concept) interfaces be considered for integration into in-vehicle devices. Where speed management is not appropriate (e.g. in urban traffic flows), or where the device does not connect with the train early enough for speed management to be viable, the device should revert to the field of safe travel interface.
That further testing and refinement of interfaces is conducted, comparing different designs, to determine the most optimum configuration.

That representatives from rail agencies take the lead to engage with road-based ITS committees, standards bodies and developers to ensure that the integration of RLX information into systems is achieved in line with good practice human factors principles.

That road and rail agencies monitor new technological developments and consider extending ITS warnings beyond in-vehicle warnings to include applications that may be used by other types of road users (e.g. smartphones, smart watches and other wearable technologies).

Recommendations for changes to RLXs in urban environments

The following recommendations are made for changes to RLXs in urban environments:

- Consideration of traffic lights as an additional control at higher risk active urban RLXs
- Trialling of pedestrian shelters with ticketing machines where the RLX is adjacent to a station.
- Trialling of RLX attendants at high risk locations during peak times, potentially utilising existing staff such as customer service officers.
- Addition of separated bicycle lanes in RLX upgrades.
- Trialling of shared space designs, using the raised ramp area with existing RLX controls (boom barriers, flashing lights, audible warnings), at specific urban locations adjacent to busy stations.

Recommendations for changes to RLXs in rural environments

The following recommendations are made for changes to RLXs in rural environments:

- Trialling of road markings to emphasise the ‘danger zone’ across the RLX.
- Further investigation into the use of mirrors at RLXs including whether they can be practically implemented and to ensure that the design will not introduce new human factors risks.
- Further investigation / field trials of improved train conspicuity, particularly focusing on drawing attention to the front of the train.

Recommendations for RLX management

The following recommendations are made to support the continuous improvement of safety at RLXs:

- **Data:** Continue efforts to increase the scope of data collection to include normal performance at RLXs, rather than collection of near miss and collision data only. This can provide real-time risk information for decision making and intervention, but will require the commitment of long-term funding to achieve.
- **Standards:** That engineering standards for RLX design promote a process that is more focused on risk management in the context of individual crossings rather than achieving consistency without reference to local conditions. Risk assessment should be conducted on a site by site basis involving appropriate experts and stakeholders (including human factors, engineering, road user representatives) and should identify solutions appropriate to the context. Where possible, data on road user behavior should be used to inform re-design.
- **Integration of systems thinking:** That consideration is given to determining how the findings from the systems analyses can be used to input to and improve the models and approaches used by RLX stakeholder agencies in Australia (e.g. ALCAM, evaluation processes for new technologies, investigation methodologies and data collection tools).
- **Shared responsibility:** That RLX stakeholders continue to build a culture of shared responsibility for RLX safety through the implementation of appropriate performance measures and incentives on all agencies around reducing risk. In addition, that stakeholders look for opportunities to combine safety goals with other priorities (e.g. community building) to gain traction.
INTRODUCTION

The rail level crossing problem

The continued incidence of rail level crossing (RLX) collisions across the world demonstrates that this longstanding problem is not being solved by current interventions. In Australia, between 2000 and 2009, there were 695 collisions between road vehicles and trains at RLXs, resulting in 97 fatalities (Independent Transport Safety Regulator, 2011). Despite various safety initiatives, in 2011 there were 49 collisions between trains and road vehicles (ATSB, 2012). Moreover, the problem is not only limited to collisions between trains and vehicles; between 2002 and 2012 there were 92 collisions between trains and pedestrians at RLXs (ATSB, 2012). Notably, the problem is not limited to Australia, with statistics showing similar problems across Europe and the United States.

Current solutions to the problem, such as grade separation and installation of boom gates at all crossings provide considerably safety improvements but are cost-prohibitive (Wigglesworth & Uber, 1991). The effectiveness of lower cost countermeasures, such as education campaigns, speed limit reductions, rumble strips, train strobe lighting and in-vehicle warnings remains largely unknown, with the evaluations to date tending to be poorly designed and lacking a sound theoretical underpinning (Edquist, Stephen, Wigglesworth & Lenné, 2009). This report noted that new cost effective approaches are needed to improve safety at RLXs, particularly for the largely unprotected (passive) crossings which make up approximately 60% of RLXs in Australia (Australian Transport Council, 2003), and was the original genesis for the project.

During the project, we have proposed that one reason why existing approaches have not fully solved the safety issues at RLXs is that a systems thinking approach has not been adopted (e.g. Read et al., 2013; Salmon et al., 2016). Specifically, it was argued that a focus on parts of the system in isolation (such as road users or warnings) has led to incremental design changes that can have only a limited impact. Moreover, the emergent behaviours brought about by different RLX interventions have not been fully considered. An absence of systems thinking design is now widely acknowledged to represent a key issue in safety critical industries (e.g. Dekker, 2011). Despite this, there appears to be a research and practice gap whereby a systems thinking approach to road and rail safety is gaining traction in academic circles (e.g. Salmon & Lenné, 2015), but not in practice.

As a new way forward, the research program described in this report involved applying a systems analysis and design framework, cognitive work analysis (CWA; Vicente, 1999) first to analyse existing RLX systems, and then to generate, evaluate, and refine new RLX design concepts. The program of research was funded under an Australian Research Council Linkage Project grant with support from key Victorian road and rail agencies and operators. The overall aim of the research program was to develop and evaluate new RLX designs with a view to improving behaviour and safety.

Systems thinking

Modern safety science has experienced a paradigm shift away from individual, reductionist approaches to analysing and improving safety issues and now emphasises the recognition of system influences on safety and the occurrence of accidents (Dekker, 2011; Rasmussen, 1997).

Traditionally, research into road user behaviour has focused on individuals, their information processing capabilities and

Systems thinking involves looking at the overall system, is component parts and the interactions between them, and the resulting emergent behaviours
limitations and their resultant behaviour (Salmon et al., 2010). For example, there is extensive research on the performance impacts of impairment in transport settings due to fatigue or alcohol, stress and distraction. Researchers in this field have predominantly preferred reductionist, analytical methods that aim to control as many variables as possible isolate cause and effect relationships. Studies employing the individual approach tend to view the person as a component, similar to a piece of technology, and provide recommendations for increasing the reliability of this component. Often, little consideration is given to the context of behaviour and its influence. This approach leads to proposals for behaviour change through education and enforcement measures that increase compliance with laws.

In contrast, the systems approach takes the overall system as the unit of analysis, looking beyond the individual and considering the interactions between humans and technology within a system. This view also encompasses factors within the broader organisational, social or political system in which processes or operations take place. Taking this view, safety emerges not from the decisions or actions of an individual but from interactions between humans and technology across the wider system. In the RLX context, this means that decisions and actions made at government, regulatory and rail operating company levels all play a role in RLX collisions. This calls for a more comprehensive approach to analysis and design that goes beyond simply road users and the RLX itself.

An integrated framework for analysis and design

A novel, integrated framework was developed to implement a systems approach in this program of research. A key feature was the development of a design approach to extend CWA to improve its ability to inform system design. This approach, the Cognitive Work Analysis Design Toolkit (CWA-DT), combines the strengths of the CWA framework with the sociotechnical systems approach to design (e.g. Cherns, 1976; 1987; Clegg, 2000). Heavily aligned with systems thinking, sociotechnical systems theory aims to support the design of systems that have the capacity to adapt and respond to changes and disturbances in the environment (e.g. societal, economic, physical environment).

The CWA-DT includes design tools and methods that encourage consideration of the values underlying the sociotechnical systems approach. It also considers core sociotechnical design principles, such as minimal critical specification, boundary management and joint design of social and technical elements. It intends to achieve the design of systems that can operate within their safety and performance boundaries both on implementation and in an on-going fashion through continual monitoring and re-design. Further, the collaborative involvement of experts (i.e. ergonomics professionals, designers and engineers), stakeholders (i.e. company representatives, supervisors, unions) and end users (i.e. workers or consumers) is leveraged to solve design problems, based on insights gained through CWA.

Over the course of the research program CWA and the CWA-DT were used as part of a sociotechnical systems design lifecycle to develop a series of new RLX design concepts. The design lifecycle incorporated the following phases (shown in Figure 1).
1. **Collection of data regarding existing RLX system functioning**

Data were collected on system functioning and user behaviour at both ‘active’ and ‘passive’ RLXs. Active crossings have warning devices that activate based on detection of an approaching train (e.g. flashing lights, boom gates and warning bells). Passive crossings, on the other hand, rely on static warnings of the presence of RLX only (e.g. road signs, road markings, RLX markers).

A range of data collection activities were undertaking including on-road studies of driver behaviour when driving through RLXs, cognitive task analysis interviews with drivers, a diary study of road user behaviour at RLXs, subject matter expert interviews, documentation review and in-cab train rides.

2. **Systems thinking analyses of behaviour in existing RLX environments**

The data collected were used to build models of the RLX system using CWA. Furthermore, hierarchical task analysis was applied to understand the ‘tasks’ undertaken by humans and technology at RLXs.

3. **Development and initial refinement of prototype RLX design concepts**

The researchers extracted the insights from the systems analysis and used these in a participatory design workshop involving stakeholders from the road and rail industries. The workshop resulted in a set of prototype designs which were evaluated against the models of the existing system to understand the impacts (both positive and negative) of introducing the new designs on the existing system and the extent to which the designs aligned with systems thinking and the sociotechnical systems values and principles. A refinement process was then undertaken to enhance the initial designs and address any potential negative effects.

4. **Formal evaluation of design concepts**

The final refined design concepts were evaluated in driving simulator studies and through a survey study of road users (including drivers, cyclists, motorcyclists, pedestrians and heavy vehicle drivers). Based on these findings, recommendations for future RLX designs were generated.

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**Figure 1. Overview of the phases of the research program.**

The following sections provide a summary of the key findings from each phase of the research program.
PHASE 1 of the research program involved collecting data to provide a better understanding of road user (e.g. driver, pedestrian) behaviour at RLXs, the operation of technology at RLXs and train driver tasks. In addition, the Phase 1 data collection activities were designed to provide the information required to develop CWA analyses of urban and rural RLX systems. The need for a better understanding of level crossings was particularly emphasised in a literature review completed prior to this research program commencing (Edquist et al, 2009).

Key considerations in designing the data collection activities included:

- The need to investigate the range of behaviour undertaken across both urban and rural environments, and at both active and passive crossing types;
- The need to understand the behaviour of all types of road users (rather than drivers only);
- The need to examine behaviour objectively and in naturalistic settings (as opposed to gathering subjective data post event);
- Ensuring that data collection included times when a train was present at the crossing (something difficult to control for in semi-naturalistic on-road studies, but able to be captured through survey studies and observations); and
- The need to understand the perspective of the train driver as well as road users.

571 participants were involved in Phase 1 of the research program

The specific activities undertaken in Phase 1 and key findings are summarised in Table 1 below. More information about the studies can be found in the referenced publications.
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<th>Activity</th>
<th>Methodology</th>
<th>Key Findings / Insights</th>
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<td>On-road study – Urban RLXs</td>
<td>• 20 participants drove an instrumented vehicle on 11km route in the South East suburbs of Melbourne, Victoria, incorporating 9 RLXs • Eyetracking conducted to gain understanding of where attention focussed • Provided verbal protocols ('thinking aloud') to gain insight into situation awareness • Interviewed about decision making processes at particular RLXs</td>
<td>• Complexity of the urban driving environment creates additional situation awareness requirements including the need to monitor traffic lights and their status and what is happening behind the vehicle. May shift driver attention away from RLX. • Novice drivers focussed attention more on the roadway (e.g. other cars, traffic lights, the road) than the RLX or the train, even when a train was present. • Some experienced drivers mentioned traffic queuing on the far side of the RLX as part of their decision-making process, to ensure there was sufficient space to proceed. Novices did not consider queuing. • Very small number of head checks were made on approach to RLXs, with many drivers making none at all. Appears that drivers are heavily reliant on the crossing signals to alert them to the presence of a train. Further, checking often restricted by built-up environment.</td>
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<tr>
<td>On-road study – Rural RLXs</td>
<td>• 22 participants drove an instrumented vehicle on 30km route around Greater Bendigo, Victoria, incorporating 10 RLXs • Eyetracking conducted to gain understanding of where attention focussed • Provided verbal protocols ('thinking aloud') to gain insight into situation awareness • Interviewed about decision making processes at particular RLXs</td>
<td>• Novice drivers may expect warnings (booms, flashing lights) to be present at passive crossings and therefore expect to be warned of approaching trains. • Unlike at urban crossings, driver overload is unlikely to play a role in rural RLX crashes. Rather, issues such as expectancy, schema-related errors, distraction and underload represent the key threats to safety at rural RLXs. • This is evidenced by the findings at active rural RLXs that experienced drivers made fewer head checks on approach to the RLX and were less expectant of a train being present.</td>
</tr>
<tr>
<td>Study Type</td>
<td>Participants</td>
<td>Description</td>
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<tr>
<td>On-road study – Urban</td>
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<td>Participants walked a predetermined route at one of three RLX sites in the South East suburbs of Melbourne. Provided verbal protocols ('thinking aloud') to gain insight into situation awareness. Interviewed about decision making processes at particular RLXs. Pedestrians most concerned about gathering information about whether a train is approaching, rather than focusing on warnings / barriers. Checking behaviour occurred, even when warnings not activated. Assumption of single train approaching. RLXs operate differently to signalised road intersections, potentially leading to inaccurate assumptions about operation.</td>
</tr>
<tr>
<td>Pedestrian observations</td>
<td>370</td>
<td>Crossing users (333 pedestrians and 37 cyclists) were observed over approximately 30 hours of observations at the 7 RLX sites in Melbourne. Pedestrians were observed to walk outside of the predefined path and a small number avoided the pedestrian crossing facilities altogether, crossing using the roadway. A number of pedestrians increased their walking pace at the onset of the bells.</td>
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<tr>
<td>Diary study</td>
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<td>Participants (drivers, motorcyclists, cyclists and pedestrians) completed a survey every day over a two-week period regarding their encounters and decision making at RLXs in Victoria. Different road users negotiate RLXs in different ways. They draw on varying personal experience, identify distinct cues and possess different situation awareness. Visual information (e.g. flashing lights) was more influential for motorists, whereas pedestrians and cyclists relied more on auditory information (e.g. bells). Pedestrians were more likely than other road users to violate active RLX warnings and/or cross before an approaching train. Reasons for noncompliance differed between road users: pedestrians crossed before a train when in a hurry, particularly if adequate ability to run across the tracks and sufficient visibility to assess train time-to-arrival, whereas cyclists’ and motorists’ main reason was being too close to crossing to stop safety when warnings activated.</td>
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- A number of cyclists failed to dismount before crossing using the pedestrian facilities.
- 14 pedestrians accessed activated crossings using emergency exit gates.
- Behaviours indicated users searched for comfort, a sense of control over the situation and engaged in social behaviours with other users at the crossing (e.g. communication, competition, cooperation).

### In-cab observations

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<td>3 researchers undertook cab rides between Melbourne and Bendigo to gain familiarisation with train driver perspective of RLXs</td>
<td>Train drivers contribute to RLX safety through actions such as using whistle to provide additional warnings, maintaining speed to ensure constant warning time, watching for road users approaching the RLX, checking to ensure that activate warnings are operational.</td>
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of the 5th International Conference on Applied Human Factors and Ergonomics, Kraków, Poland.
PHASE 2 of the research program involved the application of systems-based analysis approaches to integrate the data from Phase 1 and develop an exhaustive description of active and passive RLX systems. These included CWA and hierarchical task analysis (HTA). These approaches were selected because the outcomes of each describe the system in a different but complementary manner, which is particularly powerful for system design and evaluation. For example, CWA describes the system formatively, meaning that it models what could potentially happen. While HTA describes the system normatively, meaning that it describes what should occur for successful performance.

Cognitive work analysis

CWA (Vicente, 1999) is a systems analysis and design framework that has been used extensively in the design and analysis of safety critical systems. CWA was developed at the RISØ National Laboratory following the realisation that most adverse events in nuclear power generation involved non-routine scenarios with which workers were unfamiliar and designers had not anticipated. Therefore, CWA was intended to provide a framework to underpin the design of systems that give operators the flexibility to adapt during abnormal situations that are unanticipated by designers. Vicente (1999) describes the philosophy of CWA as enabling the worker to ‘finish the design’.

An important feature of CWA is that it provides analysis tools that identify the constraints present within a system and how these constraints restrict behaviour. The identification and understanding of constraints allows the exploration of the possibilities for changing behaviour through the removal of existing constraints, addition of new constraints, or through changing the nature of constraints.

The CWA framework comprises five separate analysis phases. A brief description of each of the phases employed and the resulting findings are given below.

Overview of CWA phases

Work Domain Analysis

Work Domain Analysis (WDA) is typically the starting point of the analysis. It is used to provide a detailed description of the system, independent of both particular human actors and particular events. It describes the environment within which users interact. In this case the analysis was used to understand an ‘active’ RLX system, and a ‘passive’ RLX system. It uses the abstraction hierarchy method to describe the system under analysis across the following five hierarchical levels (see Figure 2 for a summary of the active RLX WDA).

- Functional purposes (overall purpose of the RLX system, e.g. separation of road and rail traffic, protect road and rail users).
- Values and priority measures (the measures that are used by RLX stakeholders to assess system performance, e.g. crashes, efficiency, reliability).
- Generalised functions (the functions that are required for an RLX to achieve its functional purposes, e.g. alert road user to presence of a train, maintain separation between train and users).
- Physical functions or affordances associated with each physical object in the RLX system (e.g. a flashing light ‘provides warning of approach train’).
- Physical objects comprising the RLX system (e.g. flashing lights, boom gates, the road).
The ‘nodes’ (boxes) at each level of the WDA are connected by ‘means-ends’ links (lines). These links denote the relationships between nodes whereby those at the lower levels support those at the higher levels of the hierarchy. For example, reading from the bottom of Figure 2 upwards, the ‘Road and rail infrastructure’ (such as flashing lights) provides the function to ‘Warn, alert, cue or prompt’, which supports the general function of ‘Alert to presence of the train’. This function then supports the value and priority measure of ‘Minimise collisions’ which supports the higher functional purposes of ‘Protect road users’ and ‘Protect rail users’. The means ends can be applied to any node at any level in the abstraction hierarchy.

Figure 2. Summary WDA for active RLXs.

Key findings and insights

- There are multiple competing functional purposes that the system is attempting to achieve simultaneously. For example, maintaining priority access for rail traffic whilst minimising delays to the road network is difficult to achieve, especially on busy urban rail lines where warnings may remain active for extended periods of time while multiple trains traverse a crossing. This challenge is likely to intensify with both train frequency and traffic volumes continuing to increase.

- While seven values and priority measures were identified (e.g. minimising collisions, minimising risk), it is questionable the extent to which these are currently being satisfactorily achieved (both in Australia and internationally), and even whether they can be measured using current approaches. For example, it is debateable whether the road and rail sectors possess an accurate understanding of level of risk associated with specific RLXs and whether there is an accurate picture regarding numbers of road rule violations and near misses at RLXs.

- The generalised functions level highlights that various combinations of failed functions can lead to RLX collisions; there are many ways in which collisions can occur. For example, the system failing to alert the road user to the presence of a train represents one failed function that can cause a collision. On the other hand, many functions could also fail in a way that leads to a collision. For example, poor maintenance could lead to the active warnings not working and road users not being warned of the approaching train.
A number of generalised functions are not well-supported by the lower levels. For example, the WDA showed few physical objects to support the function of performance monitoring and education, and maintenance of traffic flow is not well supported in urban environments.

Control task analysis

Control Task Analysis (ConTA), describes the activity required to achieve the purposes, priorities and values and functions of a work domain (Naikar, Moylan & Pearce, 2006). Rasmussen’s decision ladder (cited in Vicente, 1999) is one approach that is used for the ConTA phase. The decision ladder is used to examine tasks and associated decision making processes, identifying information requirements, goals, and short cuts through the decision making process.

In the present study the ConTA phase was used to analyse the stop or go decision from the point of view of road users at RLXs including drivers, pedestrians, cyclists, and motorcyclists. The analysis was based upon the data gathered in the diary study.

Key findings and insights

- Many sources of information are used by road users to become aware of an approaching RLX and to inform their stop or go decision. In addition to expected sources of information, such as signage, flashing lights, boom gates and the train itself, other pieces of information reportedly used included the behaviour of other road users, judgements about own behaviour (such as ‘what is my current speed?’), and personal triggering features such as vegetation or a particular building.
- Motorised users (drivers and motorcyclists) are more likely to use visual information such as flashing lights and booms in making the decision to stop or go with auditory information rarely used. In contrast, pedestrians and cyclists rely more on auditory warnings.
- When RLX users acted in a way that was compliant with the road rules, the most frequently reported goal of motorcyclists and pedestrians was safety, whereas the most frequently reported goal of cyclists and drivers was compliance.
- When RLX users acted in a way that was non-compliant with the road rules, a more varied set of goals was reported. Drivers and pedestrians most frequently reported that efficiency was their primary goal, whereas for motorcyclists it was split between efficiency and getting to their destination. For cyclists, the goals of safety, efficiency and getting to their destination were equally most important.
- For pedestrians, the more information they had access to regarding the train (e.g. its location, speed), the more likely they were to violate.

Strategies analysis

The strategies analysis phase is used to identify each of the different ways in which functions can be achieved.

In the present study, the Strategies Analysis Diagram (SAD; Cornelissen, Salmon, Jenkins & Lenné, 2013) method was used for the strategies analysis phase. This builds on the WDA outputs to examine the range of strategies that can be undertaken by different types of user. An important feature of this analysis is that it identifies all of the possible ways in which tasks can be undertaken by looking at the constraints within the systems and the latitude for behaviour that they create. For example, for the task of identifying an approaching train the strategies analysis identifies all of the different ways in which users can fulfil this task, such as through seeing the flashing lights or the train itself, through hearing the train, or through monitoring the behaviour of the traffic in-front of one’s own vehicle.
Key findings and insights

- Multiple strategies for getting through an RLX were identified for each road user. This demonstrates the flexibility that the existing RLX design enables, particularly for non-motorised users such as pedestrians and cyclists.
- The information provided by warnings is generic rather than specific (i.e., there is a train coming). The analysis suggests that a number of the strategies adopted by users would be better informed through the provision of more specific information, such as time to arrival, number of trains approaching, and time that user will be delayed at the crossing. Indeed, other strategies are employed by users to attempt to seek this information, such as pedestrians looking down the track and attempting to predict time to arrival.
- There are potential conflicts between the strategies adopted by different users. For example, strategies adopted by one form of user (e.g., pedestrians crossing via the road) can impede or prevent a strategy for another form of user (e.g., drivers attempting to traverse the RLX).
- The physical use of infrastructure by non-motorised users was an interesting facet of the strategies identified. For example, cyclists using fencing or the boom barrier to support their balance when stopped. Interestingly, there are no dedicated facilities to support non-motorised users in tasks such as maintaining balance and sheltering from rain. This lack of support for comfort may encourage users to continue through the crossing as it becomes active with an approaching train.
- Given the differences in strategies undertaken by different types of road users, there is not a ‘one size fits all’ solution that will be appropriate for all types of user.

Social organisation and cooperation analysis

The Social Organisation and Co-operation Analysis (SOCA) phase is used to identify how activity is distributed amongst humans and technological artefacts within the system. This involves using the outputs from the first three phases to identify which human and non-human actors currently perform which functions, decisions, and strategies.

Once this is done, the analysts can also consider how this could be changed (for example, for technology to take on a role currently performed by humans).

Key findings and insights

- In the existing system the function of ‘System performance monitoring and education’ is predominantly undertaken by train drivers, rail operators and regulatory authorities. However, the analysis identified that monitoring and reporting could also be undertaken automatically by technological systems at the RLX as well as further support provided for road users and pedestrians to directly report issues and incidents.
- Currently, the flashing lights, boom gates, and train itself provide a warning of an approaching train, yet the road vehicle could also provide or contribute to this function through in-vehicle displays.

Worker competencies analysis

The worker competencies analysis (WCA) phase was used for the pedestrian user group only. This was determined based on the fact that this is the most vulnerable as well as diverse group. For example, pedestrians could include children, elderly users, people with disabilities and visitors and tourists with no local knowledge of RLXs or the road rules.

In the WCA phase of CWA, consideration is given to the competencies (skill-, rule- or knowledge-based) that are required to successfully undertake recurring tasks.
Key findings and insights

- Skill-based competencies were associated with the ability to perceive warnings and hazards, and physical competencies associated with traversing the RLX either on foot or using a mobility device or wheelchair.
- Rule-based competencies were related to using past experience to judge time of arrival of the train or to negotiate passing or overtaking other road users according to social norms (i.e. not passing too close, maintaining the convention of overtaking on the right-hand side, etc.).
- For knowledge-based behaviour, the competencies included knowledge that might be considered desirable. For example, that the emergency escape gate can be used to exit the track if the gates close in front of a traversing pedestrian. This knowledge would ensure that pedestrians reach a safe place in the event of a train coming and also reduces panic and uncertainty about appropriate behaviour.
- In contrast, however, too much knowledge about the operation of the RLX can mean that pedestrians undertake unsafe behaviours. For example, knowledge that the emergency exit gates can also be used to gain access to the track when a train is approaching is undesirable as they may then be used for this purpose.

Further information about the CWA findings

More information about the CWA can be found in these publications:


Hierarchical task analysis

Hierarchical task analysis (HTA; Annett, 2004) is a popular human factors method for gaining an understanding of cognitive tasks. HTA describes the activity under analysis using a hierarchy of goals, sub-goals, operations and plans resulting in an exhaustive description of the activity. Generally, HTA is used to describe how a human actor undertakes an activity. However, the method is flexible and can be used to describe both how humans and technological components (e.g. vehicles, signage, infrastructure) undertake activities. An example of this use of HTA from a systems perspective for the operation of actively controlled RLXs is discussed below.

HTA for actively controlled RLXs

The high level tasks identified for the operation of an actively controlled RLX are shown below, along with the actors who are involved in fulfilling the tasks.

<table>
<thead>
<tr>
<th>Task no.</th>
<th>Task</th>
<th>Undertaken by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control vehicle</td>
<td>Road users</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Train driver</td>
</tr>
<tr>
<td>2</td>
<td>Detect presence of train</td>
<td>RLX</td>
</tr>
<tr>
<td>3</td>
<td>Detect presence of RLX</td>
<td>Train driver</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Road users</td>
</tr>
<tr>
<td>4</td>
<td>Detect presence of road users</td>
<td>Train driver</td>
</tr>
<tr>
<td>5</td>
<td>Announce presence of train</td>
<td>RLX</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Signage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Train driver</td>
</tr>
<tr>
<td>6</td>
<td>Detect presence of train</td>
<td>Road user</td>
</tr>
<tr>
<td>7</td>
<td>Stop vehicle at rail level crossing</td>
<td>Road user</td>
</tr>
<tr>
<td>8</td>
<td>Deactivate RLX warnings/controls</td>
<td>RLX</td>
</tr>
<tr>
<td>9</td>
<td>Traverse RLX</td>
<td>Train Driver</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Road user</td>
</tr>
</tbody>
</table>

In HTA, each high level task is broken down into sub-tasks and operations (explaining the order in which tasks should be undertaken). The sub-tasks for ‘Detect presence of a train’, when undertaken by the road user, are shown below. The plan for this sequence is ‘Do 6.1-6.4 as required until 6.5, then EXIT’.

<table>
<thead>
<tr>
<th>Task no.</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Use active early warning signage</td>
</tr>
<tr>
<td></td>
<td>6.1.1 Look for signage</td>
</tr>
<tr>
<td></td>
<td>6.1.2 Detect flashing lights</td>
</tr>
<tr>
<td></td>
<td>6.1.3 Interpret flashing lights</td>
</tr>
<tr>
<td>6.2</td>
<td>Use RLX flashing lights</td>
</tr>
<tr>
<td></td>
<td>6.2.1 Look for flashing light assembly</td>
</tr>
<tr>
<td></td>
<td>6.2.2 Detect flashing lights assembly</td>
</tr>
<tr>
<td></td>
<td>6.2.3 Interpret flashing lights assembly</td>
</tr>
<tr>
<td>6.3</td>
<td>Use RLX boom gates</td>
</tr>
<tr>
<td></td>
<td>6.3.1 Look for boom gates</td>
</tr>
<tr>
<td></td>
<td>6.3.2 Detect RLX</td>
</tr>
<tr>
<td></td>
<td>6.3.3 Interpret RLX</td>
</tr>
<tr>
<td>6.4</td>
<td>Look for train</td>
</tr>
<tr>
<td></td>
<td>6.4.1 Look down train tracks either side of RLX</td>
</tr>
<tr>
<td></td>
<td>6.4.2 Detect approaching train</td>
</tr>
<tr>
<td></td>
<td>6.4.3 Interpret approaching train</td>
</tr>
<tr>
<td>6.5</td>
<td>Understand that train is approaching</td>
</tr>
</tbody>
</table>
Human error identification for actively controlled RLXs

Once tasks have been decomposed into sub-tasks, human error identification approaches such as the systematic human error reduction and prediction approach (SHERPA; Embrey, 1986) can be used to identify and analyse the types of human errors that may arise during the task. SHERPA involves identifying potential error types (Action errors, Checking errors, Retrieval errors, Communication errors and Selection errors). For each error identified, the SHERPA process involves analysing the consequences of the error, how it could be recovered, the probability of the error, its criticality and how it could be remedied. An example SHERPA analysis for the error ‘Road user fails to comprehend approaching train’ is shown below.

<table>
<thead>
<tr>
<th>Task</th>
<th>Error Mode</th>
<th>Error Description</th>
<th>Consequence</th>
<th>Recovery</th>
<th>P</th>
<th>C</th>
<th>Remedial Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.1. Look for</td>
<td>R1</td>
<td>Road user fails to look for flashing light</td>
<td>Road user fails to comprehend</td>
<td>Task</td>
<td>6.3.1 Medium</td>
<td>High</td>
<td>- In-vehicle reminder system</td>
</tr>
<tr>
<td>flashing light assembly</td>
<td></td>
<td>light assembly</td>
<td>approaching train</td>
<td></td>
<td></td>
<td></td>
<td>- Runway red lights in stop line (in-road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>studs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Traffic lights linked to RLX</td>
</tr>
</tbody>
</table>

The full SHERPA analysis conducted for actively controlled RLXs demonstrated that the current system design is highly reliant on road users to undertake critical tasks successfully, without making errors. In addition, due to the time criticality of the interaction at RLXs, there is often little opportunity for recovery from error.

Key risks identified for RLXs

Based on the data collection activities, the CWA, HTA and SHERPA analyses, a set of key risks and contributing factors were identified for existing RLX designs (passive and active). These are described below.

- Road users not aware of upcoming RLX (e.g. through looked but failed to see errors, expectancy issues, distraction)
- Road users not aware of RLX warnings (e.g. through looked but failed to see errors, expectancy issues, distraction)
- Road users not aware of approaching train (e.g. through looked but failed to see errors, expectancy issues, misinterprets warnings)
- Road user doesn’t check for trains sufficiently
- User doesn’t detect a second or subsequent train
- Road user misjudges the speed or distance of the train
- Road user chooses to cross when warnings activated / a train is approaching
- Road user queues or short stacks on the RLX
- Failure of RLX warnings (e.g. wrong-side failure)
- Visual clutter / distractions in environment (in urban environments)
- Monotonous environments (e.g. in rural environments), task under-engagement
- Congestion
- Reluctance to stop
- Frustration
- Expectancy
- Time pressure
- Panic
DEVELOPING INNOVATIVE DESIGNS

Having collected a wealth of novel data on RLX operation and risk, and applied systems thinking analysis methods, PHASE 3 of the research program involved the development of new, innovative designs for RLXs. The intention was to develop design solutions for the key risks identified in Phases 1 and 2 and also to develop more holistic designs that catered for the needs of all end-users. The design phase was driven by the application of the CWA-DT tools for participatory design. The process for generating new designs is described below.

Insights

The CWA-DT places importance on the translation of ‘insights’ gained from the CWA analysis into design solutions. Insights include both non-obvious inferences from the evidence provided in the analysis and more obvious findings about the system that the researcher considers important for the design process. The categories of insights used in the CWA-DT include assumptions (underlying, implicit assumptions, beliefs and hypothesis), leverage points (opportunities for system improvement), metaphors, scenario features and design solutions. Examples of each are shown in Table 2. Insights were documented during the data collection and analysis processes and during the design planning process.

Table 2. Examples of insights identified from the analysis

<table>
<thead>
<tr>
<th>Insight type</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumption</td>
<td>An underlying assumption upon which the system, or a part of the system is based. Includes hypotheses and beliefs underlying how the system functions.</td>
<td>That we can’t fix safety without impacting on efficiency.</td>
</tr>
<tr>
<td>Leverage point</td>
<td>An aspect within a system which if changed in a small way, could produce big changes across the system (Meadows 1999) or any other opportunity for system improvement.</td>
<td>How can the road vehicle be used to provide warnings to the driver?</td>
</tr>
<tr>
<td>Pain point</td>
<td>Problems or issues that are identified during the analysis. They may be points of frustration for users, conflicting goals between users or problems such as information bottlenecks in organisational systems.</td>
<td>Expectancy plays a key role in user behaviour at rail level crossings. Drivers in rural settings often experience RLXs with no trains present, and therefore are not expecting to see a train.</td>
</tr>
<tr>
<td>Metaphor</td>
<td>A subject that can be substituted for, or compared with, the existing system or an aspect of the system, on a symbolic level.</td>
<td>Consideration of how ‘separation’ is achieved in other industries or areas (e.g. air traffic control).</td>
</tr>
<tr>
<td>Scenario feature</td>
<td>A feature of a potential scenario that the analyst feels is important to capture. Examples include a type of actor, attributes of an actor, a type of task, an environmental disturbance or influence, etc.</td>
<td>Rain / wet weather influences behaviour, particularly for pedestrians.</td>
</tr>
<tr>
<td>Design solution</td>
<td>A proposed design or feature of a design identified by the analyst/s.</td>
<td>To draw attention to the RLX and reduce distractions on approach to urban RLXs, a raised platform could be used in conjunction with a clear way before the crossing, including a ‘no parking’ zone.</td>
</tr>
</tbody>
</table>
Design planning

The design planning stage was undertaken over two days. This involved the research team participating in a workshop to draw together the analysis findings and discuss the initial insights gained from this. In addition, the design team used prompt questions from the CWA-DT to generate new insights.

A total of 209 insights were generated. A prioritisation process was undertaken by the research team to identify those most likely to prompt effective new designs for improving safety at RLXs. The more highly prioritised insights were then used to develop the materials for the participatory design activities used in the workshop.

In addition, the researchers defined the scope, objectives and measures of success for the design process. This was documented in Design Brief and Design Criteria documents. Further, a Design Tool Selection Matrix was used to select the most appropriate tools and activities to be used in the workshop. The tools selected were:

- Assumption crushing – to promote lateral thinking
- Inspiration cards – to communicate findings of the research
- Personas – to communicate findings of the research and promote empathy
- Scenarios – to communicate findings of the research and an understanding of context
- Metaphorical Design – to promote lateral thinking
- The Impossible Challenge Exercise – to promote thinking outside of usual constraints (time, budget, etc.)
- Sociotechnical Values Cards – to introduce and promote sociotechnical thinking

A Design Brief was developed during the design planning stage. The scope was constrained to improve the at-grade interface rather than the development of grade separation options (i.e. the construction of bridges or tunnels). Further, the focus was described as improving or shaping desired behaviour rather than improving technological reliability. Further, the design process was determined to be focussed on improving design for ‘well intentioned’ road users rather than to directly address intentional efforts to circumvent the system. Similarly, the designs developed were not intended to focus on reducing incidents involving intentional self-harm at RLXs; however, it was noted that it would be beneficial if design concepts introduced some positive indirect effects on such behaviour.

Idea generation workshop

18 participants attended the two-day idea generation workshop. Participants were representatives of RLX stakeholder organisations (e.g. government departments, safety regulators, road user peak bodies, transport investigators) and those with a professional interest in the research (e.g. HFE professionals, researchers, designers). Participants engaged in the workshop activities and generated over 150 individual design ideas (see Figure 3).
Participants then worked in groups to combine these individual ideas into more comprehensive design concepts, either for rural or urban RLXs. An example is shown in Figure 4. As a result of this process of combining ideas, 11 complete design concepts were developed and then prioritised by the group.

**Desktop evaluation of design concepts**

The highest ranked five design concepts of the 11 created were selected by the research team for evaluation. The remaining design concepts were not selected for further evaluation based on the research teams’ judgements regarding alliance with systems thinking, practicality, and likelihood of implementation.

The initial evaluation process involved three core activities: insertion of concepts into the abstraction hierarchy, identification of user errors, and evaluation against sociotechnical systems values and principles. This enabled the evaluation to consider the extent to which the designs
aligned with systems thinking along with the likely impact and emergent behaviours associated with each design concept.

Insertion of the concepts into the RLX WDA involved adding the features of each design concept (e.g. in-vehicle display, new road markings, rumble strips) into the physical object level of the WDA, removing any nodes as appropriate, and then remodelling the means-ends relationships. Following this, the impact of each new object was assessed by summing the following at each level:

- **New nodes:** e.g. the new physical object ‘optimal speed to avoid train in-vehicle display’ would ‘communicate optimal speed’ and ‘provide distance to RLX’ notification.
- **Support for existing nodes:** e.g. the new physical object ‘in-vehicle warning display’ would provide support for the existing function of ‘alert user to the presence of train’.
- **Appropriate restriction:** e.g. the new physical object ‘default closed pedestrian gates’ would appropriately restrict (pedestrian) traffic flow which in turn would support the function of ‘maintain road and rail user separation’.
- **Negative influence:** e.g. the new physical object ‘speed limit reduction signs’ would have the effect of slowing traffic through RLXs which in turn may negatively influence the ‘maximise efficiency’ value and priority measure.

Identification of user errors for each design concept was achieved by applying the Systematic Human Error Reduction and Prediction Approach (SHERPA) (Embrey, 1986) to predict the likely errors that would arise when users interacted with the new RLX design. Initially, one analyst applied SHERPA to RLXs generally, and then to each design concept. The output was a series of likely errors for each concept, including a description of each error and the associated consequences, ratings of likelihood (low, medium, high) and probability (low, medium, high) and potential remedial measures. Metrics such as number of existing potential errors reduced by the new design concept as well as new errors introduced were calculated.

The evaluation against sociotechnical systems theory values and principles involved the research team considering each design concept and providing a rating of 1, 2 or 3 (low, medium, high) in relation to the principles, using the indicators provided in Table 3.
Table 3. Sociotechnical systems theory content principles and indicators used in desktop evaluation

<table>
<thead>
<tr>
<th>Content principle</th>
<th>Indicators / measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tasks are allocated appropriately between and amongst</td>
<td>• Users are provided with appropriate tasks, i.e. not monotonous tasks that can be performed by technology with human supervision, but those that provide appropriate challenge.</td>
</tr>
<tr>
<td>humans and technology</td>
<td>• Users are given tasks where there is unpredictability such that judgment and interpretation is needed.</td>
</tr>
<tr>
<td>Useful, meaningful and whole tasks are designed</td>
<td>• Users are given whole tasks, rather than fragmented pieces of tasks to perform.</td>
</tr>
<tr>
<td></td>
<td>• Users perceive the tasks they are performing to be meaningful or useful.</td>
</tr>
<tr>
<td>Boundary locations are appropriate</td>
<td>• Boundaries or divisions between users or user groups are based on whole processes.</td>
</tr>
<tr>
<td></td>
<td>• Boundaries do not impede sharing of knowledge and experience.</td>
</tr>
<tr>
<td>Boundary are managed</td>
<td>• The design facilitates supervisors, users or user groups to manage the boundaries or interfaces with other users or groups.</td>
</tr>
<tr>
<td></td>
<td>• Boundary management incorporates buffering from external disturbances or changes in the wider environment.</td>
</tr>
<tr>
<td></td>
<td>• The design empowers users to define the rules and processes that constrain their activities.</td>
</tr>
<tr>
<td>Problems are controlled at their source</td>
<td>• The design facilitates the detection of, and recovery from problems (including negative behaviours) at the time and place at which they occur.</td>
</tr>
<tr>
<td></td>
<td>• The design provides people with the competency and authority to control problems.</td>
</tr>
<tr>
<td>Design incorporates the needs of the business, users</td>
<td>• The design meets identified business needs.</td>
</tr>
<tr>
<td>and managers</td>
<td>• The design meets identified user needs.</td>
</tr>
<tr>
<td>Intimate units and environments are designed</td>
<td>• The design creates a feeling of being in a small / intimate environment.</td>
</tr>
<tr>
<td></td>
<td>• Where teams or groups are created, these are small to provide opportunities for social interaction / social cohesion / a feeling of belonging.</td>
</tr>
<tr>
<td>Design is appropriate to the particular context</td>
<td>• Local features / issues are taken into account in the design or the design can be customised for local implementation.</td>
</tr>
<tr>
<td></td>
<td>• The design is created for the specific design brief, rather than being an off-the-shelf solution.</td>
</tr>
<tr>
<td>Adaptable is achieved through multifunctionalism</td>
<td>• The design promotes multi-skilling of individuals.</td>
</tr>
<tr>
<td></td>
<td>• The design promotes collaboration between individuals with varied skills and experience.</td>
</tr>
<tr>
<td>Adaptable is achieved through flexible structures and</td>
<td>• The design incorporates units or groups which are multi-skilled and flexible to changing demands.</td>
</tr>
<tr>
<td>mechanisms</td>
<td>Information is provided where action is needed</td>
</tr>
<tr>
<td></td>
<td>• Information systems are consistent with the way work will be organised.</td>
</tr>
<tr>
<td></td>
<td>• Information is presented in line with the mental model of the decision maker, or any conflicts are resolved through additional methods such as training.</td>
</tr>
<tr>
<td></td>
<td>• The information gets to the person making the decision.</td>
</tr>
<tr>
<td></td>
<td>• The information gets to the person making the decision at the right time.</td>
</tr>
<tr>
<td></td>
<td>• The information provided is in an appropriate format and at an appropriate level of detail to enable the receiver to make the decision</td>
</tr>
</tbody>
</table>
and take necessary action. The information is usable, not unnecessarily complex.
• Information is provided to users about what is expected of them and feedback is provided on their progress towards targets / measures.

| Means for undertaking tasks are flexibly specified | • The design is not overly specified enabling it to evolve over time in line with changing user needs and preferences.  
• The means for carrying out tasks and activities is not unnecessarily restrictive.  
• The design empowers users to solve their own problems and develop their own ways of achieving outcomes. |
| Authority and responsibility are allocated appropriately | • The design places appropriate authority on users.  
• The design engenders appropriate levels of responsibility.  
• The design minimises status differentials between groups or individuals. |
| System elements are congruent | • Elements of the design are in harmony with one another – users will not perceive a conflict.  
• The design is in harmony with the existing system or changes to the existing system are planned to facilitate the implementation of the new design.  
• Targets and measures are fair and reasonable and support the design of work. For example, if team working is part of the design, information and reward on individual performance is not appropriate.  
• Designs are incorporated within, and consistent with, the wider management system. |

The ratings were then aggregated giving each design concept a total score. Importantly, the desktop evaluation identified a number of design refinements that could address potential negative impacts identified, reduce potential errors and improve alignment with sociotechnical systems theory.

Design refinement

Ten participants, again representatives of RLX stakeholder organisations and those with a professional interest in the research, attended a follow-up one-day workshop to further refine the design concepts. Prior to the workshop, participants were provided with a written summary of the top five ranked design concepts and a summary of the overall evaluation findings. A detailed overview of each concept was provided, following which participants engaged in a series of activities, including:
• reviewing suggested design improvements identified during the evaluation process;  
• identifying additional design improvements; and  
• evaluation and final ranking of concepts following the inclusion of design refinements deemed to be practical and appropriate.

The output of the concept refinement workshop was four refined design concepts (with two of the original five concepts being integrated through the refinement process).

Researcher design concepts

Subsequent design workshops involving researchers experienced in CWA were undertaken to conduct the detailed design of aspects of the designs (e.g. of in-vehicle interfaces). In addition to using the sociotechnical systems theory philosophy to design, the in-vehicle interface design component also applied the principles of ecological interface design (EID) where feasible.
EID makes claims that interfaces will be superior over traditional designs because they:

- reduce human information processing demand (by making the constraints in the world more explicit);
- reduce memory demand (because all of the required information is placed in the world);
- reduce errors (by making the appropriate action more obvious and explicit); and
- are easier to learn (because of the combination of the above).

The design of ecological interfaces to support stop/go decisions at RLXs is focused on making the world constraints obvious to road users and train drivers. EID builds upon the CWA, which identifies all of the constraints that affect behaviour and functioning at RLXs.

In addition to detailed design of existing concepts, two additional designs were developed for further evaluation and testing: the urban design concept ‘Community courtyard crossing’ and the rural design concept ‘Ecological interface design’, which used the principles of EID but applied to the design of the infrastructure rather than an in-vehicle device.
Outcomes of the design process

Once the detailed design was completed, 3D drawings were created for each of the designs that involved infrastructure changes (as opposed to in-vehicle devices).

A detailed description of each concept is provided below.

Urban RLX design concepts

**Comprehensive risk control crossing**

**Design philosophy**

This concept uses a combination of safety risk controls and aspects to improve amenity, particularly for pedestrians. It focuses on drawing the attention of road users to the presence of the RLX and approaching trains (e.g. through the addition of traffic lights, advanced warning signs, in-road studs and default closed gate for pedestrians). It also aims to avoid queuing on the RLX or to mitigate its consequences (e.g. using traffic light coordination, ‘hold’ and ‘keep tracks clear’ signs for approaching traffic, an awareness campaign, emergency lane and no standing zone on RLX exit), as well as to enforce rules (e.g. through camera enforcement and channelised fencing for pedestrians). Finally, it provides convenience and amenity to waiting pedestrians (e.g. through an all-cross pedestrian phase, shelters, a community hub, ticketing machines and cafés at or near the waiting area).

**Key features**

- Traffic lights in addition to current RLX flashing lights and boom barriers.
- Traffic light coordination to control up and downstream traffic.
- Camera enforcement, linked to traffic lights – with automatic fines via number plate recognition.
- Revenue collected from fines is used to cover the costs of cameras and upgrades.
- Advance warning signs.
- In-road studs that light up when warnings are activated.
- Cyclist box at the head of the traffic queue.
- Yellow box markings to highlight danger zone.
- An emergency lane and ‘no standing’ zone to provide exit from the RLX for queued drivers, with active bollards linked to the warnings to avoid everyday use of the lane.
- A ‘skirt’ underneath the boom gate to increase its physical presence and use this to provide safety messages.
- Channelised pedestrian fencing to avoid use of the road to cross the RLX.
- A default closed gate for pedestrians that is locked when train is approaching - with a button for accessibility for people with disabilities (button is lit up green when unlocked, and red when locked).
• Where possible, unlock pedestrian gates between trains (while road booms remain closed) to enable pedestrians to cross for longer.

• An all-cross traffic phase for pedestrians – with official diagonal paths across the RLX.

• RLX supervisors / attendants at locations and times of higher risk (e.g. crossings with many near misses, peak times). Their role would be to supervise the RLX, assist in emergencies, report maintenance and safety issues to management, and provide customer information to passengers entering / departing stations

• Active advance warning signs for trucks / buses.

• Signs displaying ‘hold’ and ‘keep tracks clear’ (activated by loop to detect traffic queues).

• ‘Break the chain’ promotion / awareness campaign to discourage queuing on the crossing.

• Vehicle-to-vehicle collision avoidance to avoid rear-end crashes between road vehicles near the crossing that may lead to congestion.

• Set back / offset platforms – would reduce the speed of trains through the RLX.

• Convenience and amenity for waiting pedestrians such as a shelter, community hub, ticketing machine. Advertising may be used to offset costs.

• Café’s near waiting area – with displays informing users about the RLX and its progress towards meeting its objectives – e.g. information about near misses, incidents, risk level, efficiency. Encourage conversations at the café about the RLX.

• A display at the train station platform that gives pedestrian users information about the driver of the last train to traverse the RLX (e.g. their name, something personal about themselves) – to encourage reflection on how behaviour such as crossing in front of the train might affect the driver personally.

• Constant recording and monitoring of road users to better understand behaviour and system functioning with the findings used to identify safety issues and inform education initiatives.
Intelligent level crossing

The field of safe travel (Gibson & Crooks, 1938)

Design philosophy

This concept is based around the use of new and emerging intelligent transport system (ITS) technologies to better optimise the functioning of the transport system by improving communication and coordination between road and rail. It provides decision support systems to road users (via in-vehicle interfaces, smartphones or dynamic displays), reduced delays and enforcement of stopping when collisions are predicted. The design of the in-vehicle display for drivers was based on EID, specifically on Gibson & Crooks’ (1938) field of safe travel theory. This posits that drivers operate by perceiving a dynamic envelope in front of their vehicle of the safe path ahead, based on the surrounding traffic and hazards, and seek to preserve an acceptable ratio of stopping distance to the boundary of the perceived safe field.

Key features

- ITS transmission to vehicles.
- An in-vehicle display providing auditory and visual cues, based on field of safe travel theory, with the following features:
  - On approach to the RLX when a train approaching, the display provides an alert tone and a visual train icon appears on the display.
  - A green ‘tongue’ appears on the display to indicate the safe field on the road ahead.
  - As the vehicle gets closer to the RLX, black curved bars appear (in line with the stop line) to show the limit of the field.
  - When no train is approaching, the display continues to show a representation of the roadway ahead but shows no indication (i.e. no green tongue is displayed).
- The in-vehicle system automatically routes away from congested crossings or provides route advice to drivers to divert away from crossings. ITS transponder detects if the vehicle has stopped or is stuck on the RLX and provides verbal warnings / guidance to the user (e.g. to move off the RLX or leave the vehicle).
- Road signalling and controls working with train control data to predict train arrivals, and sequence with road signals for smooth traffic flow.
- ITS transmission to smartphones to provide warnings of trains.
- Dynamic displays are provided for pedestrians at the crossing displaying train information (e.g. when second trains are approaching) as well as news, weather, etc.
- Better coordination between road and rail control rooms – e.g. via data and communication links.
- Predictive stopper mode for stopping trains with automatic train protection (ATP) to avoid extended warnings and provide a constant 25 second warning for all trains.
- ATP to enforce trains stopping at the signal protecting the RLX.
- Obstacle detection system to detect heavy vehicles (only) stopped on the tracks and enforce train braking to avoid a collision.
- The ITS system predicts if a heavy vehicle is likely to collide with the train and enforces stop via the heavy vehicle’s braking system.
- The system automatically collects data (e.g. vehicle speeds on approach, train / road vehicle behavior on approach, violations, precursors) and uses algorithms to automate data analysis.
Community courtyard crossing

Design philosophy
This concept is underpinned by the notion of shared space and the prioritisation of active transport in the roadway. It also provides a vibrant space to enhance social interaction and inclusion while providing a focus of transit orientated economic and community activity. It is intended to be implemented only in locations where the crossing is also adjacent to a train station. It also provides opportunity for recovery from failures with the speed of the train slowed and the RLX supervised by railway attendents.

Key features

- A city square / courtyard feel: cafes, meeting areas & community information booths.
- A 'shared space' area adjacent to the RLX delineated by traffic lights which hold road vehicles back away from the RLX when trains are approaching.
- A speed reduction to 20km/h within the shared space for both road vehicles and trains.
- Shared space area is raised above the usual road surface level.
- Road users are expected to give way to more vulnerable road users within the shared space.
- Replacement of traditional RLX warnings such as boom barriers, flashing lights and auditory bells with RLX supervisors / attendants.
Rural RLX design concepts

Simple but strong

Design philosophy

The philosophy behind this design is to use simple and low-cost features to draw attention to the upcoming RLX and the danger posed, and to provide warning of a train approach. In addition, road user speed is managed on approach to provide more time to recover from errors.

Key features

- Gradual reduction of speed for drivers on approach – speed limit signs of 100, 80, 60, 40km/h.
- Train activates a detection loop to activate RLX signs facing road vehicles (one on approach to the RLX and one at the RLX). Signs include audible warning of bells ringing.
- The sign at the crossing has a healthy state light for monitoring by train driver.
- A high intensity flashing red light on the front of the train is activated to draw attention to the train.
- Road markings ('X Rail') and rumble strips on approach.
- Painted area just prior to crossing ‘danger zone’ – to provide a strong visual demarcation.
- Text on the RLX surface saying ‘danger zone’.
- The white centre line becomes a zig zag just prior to crossing – to break up the continuous visual line to the horizon.
- Change signage at the crossing ‘Railway crossing’ to red (facing out to approaching road vehicles, no red facing train drivers).
Ecological interface design

Design philosophy

This concept applied the principles of EID to the design of the physical RLX environment. It intends to make the constraints in the world visible to road users by emphasising the danger zone, emphasising the train as the key hazard and assisting both road users and train drivers to judge speed and distance. In addition, it slows both the road user and train to enable the system to better recover from errors.

Key features

- Train speed slowed (i.e. to 20km/h) through the RLX.
- An orange area on the road with a tongue indicating to drivers the field of safe travel when a train is approaching (this is static and does not change with the position of the train)
- Train livery (paintwork) is designed to represent a character (i.e. ironman) that conveys the speed and strength of the train to engender a sense of caution in the road user.
- Train becomes the boom barrier - barrier is painted down the side of the train.
- Road markings ‘slow’ for road vehicles.
- Poles on the side of the road and train tracks are spaced at wide intervals on the beginning of the approach and then are positioned closer together as the user (train driver and road user) get closer to the RLX. This gives the perception of going faster to encourage more cautious behaviour.
- Mirrors at the RLX reflect the train’s headlights / image towards the road, potentially using a red filter. The mirror also reflects the sound of the train horn towards approaching traffic.
GPS average speed to avoid a train

Design philosophy

This concept is underpinned by time-based separation and promotes efficiency and traffic flow as a means to also improve safety. It uses new and emerging technologies to provide road users (specifically drivers) with speed guidance that would enable them to avoid needing to stop for an approaching train.

Key features

- Underpinned by a cloud-based algorithm that senses speed data from the road vehicle and the train and calculates the speed at which the driver can proceed to avoid having to stop for an approaching train.
- Driver guidance is provided on the speedometer. Within the interface:
  - Red and green indications are used to indicate dynamic ‘safe’ and ‘unsafe’ speed zones based on the speed limit of the road and the car and train’s position.
  - The driver is informed that the unsafe speed is imposed because of the train by a train icon appearing on the display.
  - If the car’s speed moves into the unsafe zone the display flashes and an auditory tone is given to draw attention to the display.
- Route planning by the GPS to avoid RLXs or to prefer active over passive RLXs. Would provide route optimisation in urban areas (i.e. avoid congested RLXs).
- Device calculates the speed profile of the vehicle for the physical nature of the RLX to determine, for example, if the vehicle is going too fast at an RLX with limited sight distance and provide warnings accordingly.
- Where technology available, the system would auto-apply the brakes on the road vehicle where it predicts a collision will occur.
- The display provides a visual indication of the risk level or state of the RLX – e.g. display is red if it is a high risk RLX, such as one with non-compliant sighting distance for heavy vehicles.
- The system automatically collects incident / near miss data.
- Open source software is utilised to enable the system to be changed based on user needs and preferences over time. Server software would be open source.
- Forums are held with train drivers and local road users, local council staff and police twice a year to share issues and experiences at RLXs to build empathy and understanding.

When implemented by heavy vehicle companies, the design also incorporates:

- Drivers provided with aggregate data as feedback to promote social norms around safe behaviour.
- Both heavy vehicle drivers and train drivers are educated about the device and how it works.
- Discounts on insurance are provided where aggregate data collected by the device demonstrates safe or compliant use of RLXs.
Further information about the design process

More information about the design process can be found in these publications:


PHASE 4 of the research program focussed on the evaluation of the novel design concepts for RLXs.

Two key approaches were used to evaluate the proposed designs. Firstly, simulated road environments were created to test driver responses to the new designs. Secondly, to ensure that the views of other types of road users were gathered, a survey study was conducted to understand the perspectives and preferences of drivers as well as cyclists, motorcyclists, pedestrians and heavy vehicle drivers.

It should be noted that some design features were unable to be directly evaluated using the evaluation methods employed and require further investigation. These features included education campaigns, data collection systems and changes to traffic signalling away from the RLX.

Driving simulation

Three driving simulator studies were undertaken to evaluate the RLX design concept based on their impacts on driver behaviour and situation awareness, as well as participants’ subjective ratings of workload, usability and preference for the designs. Drivers responses to the new designs were compared to ‘baseline’ conditions which were simulated environments representing standard RLX designs for urban or rural areas. Simulation was used as it enabled the participants to be exposed to the new designs in an immersive environment.

Study 1: Urban RLX design concept evaluation study – 29 participants were exposed to four driving trials, experiencing the baseline design and each of the new urban designs four times (twice with no train coming, twice with a train coming).

Study 2: Rural RLX design concept evaluation study – 30 participants were exposed to five driving trials, experiencing two baseline designs (one active, one passive) and each of the new rural designs five times (three times with no train coming, twice with a train coming).

Study 3: Rural RLX specific risk scenario evaluation study – 25 participants were exposed to the same five driving trials as Study 2, with the addition of a distractor event and a simulated technology failure. This was undertaken to test the designs under high risk conditions.

All studies were conducted in a driving simulator, using Oktal SCANeR™ studio version 1.5 software (see Figure 5). The driving scenarios were presented to participants using three 40-inch monitors representing a 135° field of view from the front and two sides (1080p resolution, 60hz refresh rate). A 9.7 inch tablet screen presented standard vehicle displays (e.g. speedometer, odometer). Driving controls included a Logitech G27 steering wheel, brake and accelerator foot pedals and an adjustable driver’s seat. A 7 inch tablet screen was used to simulate the additional in-vehicle display for the evaluation of the Intelligent level crossing concept.

The measures collected included:

- Driving performance measures: mean speed, acceleration, braking pressure, time spent braking, time spent speeding, maximum speed, time spent stopped.
- Verbal protocols (‘thinking aloud’) to indicate participants’ situation awareness.
- The NASA-TLX to indicate subjective workload.
- The System Usability Scale (SUS) as a measure of usability.
- Qualitative questions about strengths and weaknesses of the designs.
- Indication of overall preference for designs.

Figure 5. Experimenter view of simulator.

Feedback all road user types

To ensure that the views and preferences of all road users were considered in the evaluation process, an online survey was distributed using recordings of the simulations, taken from the perspectives of different road users.

104 participants responded to the urban surveys, with the majority of respondents being drivers.

72 participants responded to the rural surveys, with the majority of respondents being motorcyclists.
Participants viewed video simulations of the road user traversing each RLX type. They then provided comments on the strengths and weaknesses of the designs from the perspective of their road user group and compared the designs in relation to the following criteria (derived from the values and priority measures in the WDA):

- **Safety**: Which crossing would have less collisions between trains and *<drivers / cyclists / motorcyclists / pedestrians / heavy vehicle drivers>*?
- **Efficiency**: Which crossing would be fastest to get through?
- **Compliance**: At which crossing would *<drivers / cyclists / motorcyclists / pedestrians / heavy vehicle drivers>* be more likely to stick to the rules?
- **Ease of use**: Which crossing would *<drivers / cyclists / motorcyclists / pedestrians / heavy vehicle drivers>* prefer to use?
Evaluation results for urban design concepts

The following summaries describe firstly the baseline concepts and then the new design concepts generated for urban environments. For each new design, the key findings from the evaluation process and practical considerations are provided as well as any associated recommendations. The images provided are screen shots from the driving simulator models used in the evaluation process.

**Urban baseline crossing design (existing treatment)**

**Description**

- Protected with flashing lights, half boom barriers and signage in line with AS1742.7.
Comprehensive risk control crossing

Strengths

- Simulator participants reported that they liked the traffic lights, as they provided early warning of the need to stop and provide certainty about when to proceed after train passes.
- No difference in workload reported by simulator participants compared to baseline, even though many additional warnings are present.
- Drivers, cyclists, motorcyclists, pedestrians and heavy vehicle drivers responding to the survey rated this concept highest for safety and compliance.
- Most preferred concept for pedestrians who noted the shelters, the ticket machines, the lights on the pedestrian gate as positive aspects.
- Most preferred concept for heavy vehicle drivers with separation of road users, clear warnings and the presence of RLX attendants noted as positive features.

Limitations / weaknesses

- No significant differences in driving performance of simulator participants to baseline.
- Simulator study participants rated the design less usable than baseline.
- Simulator participants reported concern about distraction and visual clutter.
- Cyclists responding to the survey reported that it remains risky for cyclists to merge with traffic over the RLX, would prefer a bicycle lane continuing through the crossing.

Practical considerations

- Risk of vandalism of shelters, the community hub, ticketing machines, etc.
- Ensuring the safety and security of the RLX attendants.
- Costs associated with employing attendants, recording of behaviour, installation of active bollards.
- Potential risks associated with implementation of active bollards – e.g. moving when a road user is nearby.
- Traffic queue loops on multi-lane roads (must ensure relevance of warning to each lane of traffic).
- Users congregating at the pedestrian shelter, community hub and café/s might lead to congestion and make it difficult for users to exit the RLX, it may also lead to distraction of drivers, particularly when first implemented.

Recommendations

- Consideration of traffic lights as an additional control at high risk active urban RLXs.
- Trialling of pedestrian shelters with ticketing machines where the RLX is adjacent to a station.
• Trialling of attendants at high risk locations during peak times, potentially utilising existing staff such as customer service officers.
• Addition of a bicycle lane to newly designed RLXs.
Intelligent level crossing

Strengths
- Simulator participants had decreased mean and maximum speed on approach to the RLX compared to baseline.
- Simulator participants had reduced mean braking pressure and time spent traversing the RLX than baseline.
- Simulator participants gave the highest usability scores (although not significantly higher than baseline).
- Provided earliest awareness of train approach (due to auditory and visual warnings occurring earlier than RLX warnings), based on simulator participants’ verbal protocols.
- Simulator participants stopped earlier on approach.
- Simulator participants rated the design as most preferred.
- Drivers responding to the survey rated this concept as most efficient and the most preferred of the new designs.

Limitations / weaknesses
- Some simulator participants reported concern that the device may be distracting (head down display).
- Some survey respondents were concerned about reliability of the technology and issues with integration into older vehicles.

Practical considerations
- Technology required to drive this intervention is not yet available.
- Needs to be integrated into commercial maps systems – not viable as a stand-alone application.
- Appropriate formats for pedestrians, cyclists and motorcyclists needs to be determined.

Recommendations
- That representatives from rail agencies take the lead to engage with road-based ITS committees, standards bodies and providers to ensure the appropriate integration of level crossing information into systems.
- That further testing and refinement of interfaces using the field of safe travel concept, with additional auditory information is undertaken to determine the most optimum configuration.
Community courtyard crossing

Strengths

- Simulator participants displayed lower speeds on approach and more gradual deceleration compared to baseline.
- Road users responding to the survey reported that having additional distance to the crossing and a raised platform was beneficial.
- Road users responding to the survey reported liking the aesthetics of the crossing.
- Pedestrians and cyclists responding to the survey rated this concept as being the most efficient (i.e. faster to get through).
- Cyclists rated this concept as most preferred.

Limitations / weaknesses

- Simulator participants experienced a longer travel time through the RLX, compared with baseline.
- Simulator participants reported significantly higher levels of mental demand and frustration and felt more rushed than for baseline.
- Simulator participants rated as less usable/less pleasant to use than baseline.
- Simulator participants tended to focus their attention on the traffic lights, rather than the train.
- Simulator participants and road users responding to the survey reported that didn’t always recognise they were approaching an RLX.
- Drivers and motorcyclists responding the survey ranked this concept as the least efficient and least preferred.
- There were mixed feelings about the shared zone, a number of simulator participants and survey respondents reported that it appeared unsafe for pedestrians and attendants, referring to a lack of trust in motorists to slow and give way to non-motorised users.

Practical considerations

- Cost of employing attendants.
- Ensuring the safety and security of attendants.
- Whether there will be sufficient pedestrian traffic to ensure the 20km/h limit is seen as legitimate by drivers, particularly at non-peak times and at night.

Recommendations

- Consider implementation of the raised hump and shared space zone surrounding existing RLXs (i.e. keeping the standard RLX warnings) for very specific station precincts with high pedestrian volumes.
Evaluation results for rural design concepts

The summaries below describe firstly the baseline concepts and then the new design concepts generated for rural environments. For each new design, the key findings from the evaluation process and practical considerations are provided as well as any associated recommendations. The images provided are screen shots from the driving simulator models used in the evaluation process.

**Rural passive baseline crossing design (existing treatment)**

Description

- Provision of give way signs, passive advance warning signs, rumble strips and line markings (X RAIL) in line with AS1742.7.

**Rural active baseline crossing design (existing treatment)**

Description

- Provision of flashing lights, passive advance warning signs, road markings, etc. in line with AS1742.7.
Simple but strong

Strengths

- Provides an active warning at lower cost than traditional flashing lights with simulator participants responding positively to the visual and auditory warnings.
- Produced greatest speed reduction in the simulator, especially when no train was approaching.
- Cyclists and drivers responding to the survey rated concept as most likely to have compliant behaviour.
- Cyclists and heavy vehicle drivers rated as safest concept, and it was rated the most efficient and preferred concept for cyclists.
- In particular, survey respondents noted the road markings (i.e. ‘danger zone’) as a positive feature.

Limitations / weaknesses

- Simulator participants reported that speed signs unlikely to be complied with (especially 40km/h), and contributed to visual clutter.
- Simulator participants indicated this design was more complex to use than the baseline designs.
- Simulator participants experienced a longer travel time through the RLX when a train was present, than experienced with active and passive baseline designs.
- Of the new designs, this concept was the least preferred by driving simulator participants and was rated significantly lower in usability compared to both passive and active baselines.
- When participants experienced the design in high risk conditions (i.e. with distractor task and a failure condition) mental workload was rated significantly higher than active baseline when a train was present.
- Participants reported significantly higher frustration compared to baseline when no train was present. This is likely due to complying to lower speed limits when no train is present.
- Drivers and motorcyclists responding to the survey reported not liking the speed reductions.
- Motorcyclists rated as the least efficient (i.e. would take the most time to traverse the RLX).

Practical considerations

- The low-cost warning device would require testing to ensure high levels of reliability, given the departure from fail-safe requirements.
- With a large number of signs there may be higher likelihood of damage and vandalism, therefore additional maintenance inspections may be required.
- Paint on the roadway can be a hazard for two-wheeled vehicles, use of a coloured aggregate instead of paint could be used.

Recommendations

- Provide clear warning of the RLX through the use road markings (i.e. ‘danger zone’).
Ecological interface design

Strengths

- Simulator participants slowed significantly compared to baseline when a train was approaching, but maintained travel speeds when there was no train.
- Simulator participants reported liking the reflector posts.
- Slower speeds of road vehicles and trains may allow recovery from error.
- Simulator participants experiencing the concept under high risk conditions rated their own performance as significantly better than active baseline when a train was present.
- Simulator participants reported lower effort was required when a train was present than active baseline.
- Most preferred of the new designs by simulator participants.
- Simulator participants reported that the train was more conspicuous.

Limitations / weaknesses

- Simulator participants indicated this design was more complex to use, and disliked the visual clutter from a combination of poles, road markings and the mirrors.
- Simulator participants experienced a longer travel time through the RLX when a train was present, than experienced with active and passive baseline designs.
- Motorcyclists and cyclists responding to the survey raised concerns about the mirrors being distracting, and their effectiveness in conditions such as sunglare and fog.

Practical considerations

- Design and placement of mirrors will require input from human factors professionals. In particular, there is a need to ensure an appropriate angle of view on approach for all road users, to avoid issues of glare from sunlight and headlights at night, and to ensure that the image provided by the mirror is appropriate for drivers to understand the risk and the need to stop.
- Impact of slowed speed on train timetabling would need to investigated and addressed. Potentially train movements could be optimised using next generation train control systems such that delays experienced by slowing around RLXs could be used to offset waiting time at other points in the journey (e.g. at crossing loops).
- Paint on the roadway can be a hazard for two-wheeled vehicles, use of a coloured aggregate instead of paint could be used.

Recommendations

- Further investigation into the use of mirrors at RLXs including whether they can be practically implemented and to ensure that the design will not introduce new human factors risks.
- Further investigation / field trials of road markings to better delineate the danger zone and the static field of safe travel.
- Further investigation / field trials of improved train conspicuity, particularly focusing on drawing attention to the front of the train (supported by recent research by Clark, Perrone, Isler & Charlton, 2016).
GPS average speed to avoid a train

**Strengths**

- Simulator participants achieved a smoother speed profile through the RLX than baseline.
- Simulator participants achieved better efficiency through the RLX when a train was present compared to the other new designs (although similar to the baseline condition).
- Simulator participants reported liking that they could avoid stopping for the train.
- Heavy vehicle drivers responding to this survey rated this concept as most efficient, most likely to support compliant behaviour and most preferred.

**Limitations / weaknesses**

- Considerable individual differences were found in responses to the device in the driving simulator, indicating it would may not be acceptable to all users.
- On average the device gave warnings (informing participants to slow) on 2 to 3 occasions (range of 0 to 6), indicating that participants may have been attempting to stay close to the limit.
- On average, participants were not compliant with the speed guidance around 30% of the time.
- Where warnings had been active for a longer period, participants slowed considerably in the final approach to the RLX to then comply with the speed guidance. This may have negative consequences for traffic flow.
- A number of simulator participants did not to intuitively understand the interface and what information was being conveyed.
- Simulator participants reported being distracted by the interface, especially as it activated quite a distance (two kilometres) from the RLX.
- Simulator participants suggested that the speed reduction was too much to be acceptable (e.g. a reduction from 80km/h in a 100km/h zone).
- Significantly higher frustration was reported by simulator participants when a train was present (the device was active) than when no train was present.

**Practical considerations**

- Technology required to drive this intervention is not yet available.
- Needs to be integrated into commercial speed management systems – not viable as a stand-alone application.
- Lower cost for road / rail agencies as does not require infrastructure changes, although will require ITS integration across road and rail systems and development and maintenance of a reliable algorithm.
- Without additional controls such as integration with active intelligent speed adaptation systems that enforce compliance with speed limits, drivers might use the information provided to speed up to ‘beat’ the train.
- Availability of GPS in rural areas may be unreliable.
- The effect of slowing on others in the traffic stream needs to be considered if not fitted in all road vehicles.
Recommendations

- That representatives from rail agencies take the lead to engage with road-based ITS committees, standards bodies and providers to ensure the appropriate integration of level crossing information into systems.
- That GPS devices use a speed management approach where viable given the environment (e.g. rural rather than urban environments).
- That further testing and refinement of interfaces to guide driver speed is undertaken to determine the most optimum configuration.
- That further research is undertaken on what speed reductions would be considered acceptable to improve compliance with the speed guidance.
Evaluation summary

Urban RLX design concepts

The below ratings provide a high level summary of the evaluation results, using a comparison to the urban baseline condition (i.e. red = worse than baseline, orange = equivalent to baseline, green = better than baseline).

<table>
<thead>
<tr>
<th>Measures</th>
<th>Comprehensive</th>
<th>Intelligent level crossing</th>
<th>Community courtyard crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximise safety (minimise collisions, trauma, injuries, near miss events, risk)</td>
<td>Green</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Maximise efficiency</td>
<td>Green</td>
<td>Orange</td>
<td>Orange</td>
</tr>
<tr>
<td>Minimise road rule violations</td>
<td>Green</td>
<td>Orange</td>
<td>Orange</td>
</tr>
<tr>
<td>Maximise reliability</td>
<td>Green</td>
<td>Orange</td>
<td>Orange</td>
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<td>Maximise conformity with standards and regulations</td>
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<td>Short-term feasibility (including cost, practical implementation)</td>
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These evaluations suggest that overall, the Intelligent level crossing concept is promising, although it may not be feasible in the short term. The Comprehensive concept is also promising, particularly the addition of traffic lights at high risk urban RLXs. Furthermore, certain aspects of the Comprehensive concept are recommended for further evaluation and testing (e.g. the use of attendants a high risk times, trialling of pedestrian shelters with ticket machines, and other community facilities).

Rural RLX design concepts

The below ratings provide a high level summary of the evaluation results for the rural design concepts, using a comparison to the rural active baseline condition (i.e. red = worse than baseline, orange = equivalent to baseline, green = better than baseline).

<table>
<thead>
<tr>
<th>Measures</th>
<th>Simple but strong</th>
<th>Ecological interface design</th>
<th>GPS average speed to avoid a train</th>
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<tbody>
<tr>
<td>Maximise safety (minimise collisions, trauma, injuries, near miss events, risk)</td>
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<td>Maximise efficiency</td>
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<td>Minimise road rule violations</td>
<td>Orange</td>
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<td>Maximise reliability</td>
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These evaluations suggest that the GPS average speed concept would be promising, however, as with the Intelligent level crossing concept, this may not be a feasible intervention in the short term. Further, design refinement is needed to ensure acceptability to users. Aspects of the Ecological interface design concept (e.g. the mirrors to reflect train approach, improving train conspicuity) and the Simple but strong concept (e.g. road markings) may provide benefits but will require field trials before implementation can be recommended.
CONCLUSIONS & RECOMMENDATIONS

RLX safety is a longstanding issue that has proved resistant to existing interventions. This research program was underpinned by the notion that safety and efficiency gains can be made through adopting a systems thinking approach. Accordingly, the research program and this report have demonstrated how such an approach can be applied to the analysis and design of RLXs.

The research has demonstrated the benefits of applying systems thinking approaches to the analysis and design of RLXs. By collecting exhaustive data regarding the behaviour of different end users and then integrating this data within appropriate systems analysis frameworks, a rich and detailed description of RLX system behaviour was produced. In the present research program this was used to generate insight into safer RLX designs; however, it is our contention that the analyses could also inform other reforms designed to increase RLX reliability, efficiency, and end-user satisfaction.

In terms of RLX safety, the analyses highlighted the different requirements of various road users at RLXs and the many contextual factors that influence behaviour. In short, there is a considerable variation in how road users interact with RLXs, and there are a range of ways in which adverse events can emerge. Design solutions aimed at car drivers will not have the same impact on heavy vehicle drivers or pedestrians. The importance of considering all road users in analysis and design is thus emphasised, as is the need to continually monitor and assess RLX system behaviour and the unique challenges faced by different users.

Importantly, the research has highlighted instances where design interventions can be used to restrict adverse events. For example, the evaluation provided evidence of the benefits that in-vehicle ITS systems can provide into the future. However, the key will be to ensure that RLX features are appropriately integrated into wider ITS systems. In the short term, the evaluation results suggest a number of countermeasures may be beneficial subject to further testing and trialling in the field.

The systems approach taken throughout this research program promotes the consideration of not only the physical environment of the RLX but also the wider environment within which RLXs are designed, operated, maintained and upgraded. As such, recommendations are made to support the continuous improvement of RLX safety more generally.

Recommendations for the introduction of in-vehicle warning devices

In general, the in-vehicle warning devices tested demonstrated considerable benefit and appeared to have acceptance from users. The following recommendations are made to support the appropriate introduction of ITS technologies for improving RLX safety:

• That both speed management (e.g. the GPS average speed concept) and guidance on the field of safe travel (e.g. the Intelligent level crossing concept) interfaces be considered for integration into in-vehicle devices. Where speed management is not appropriate (e.g. in urban traffic flows), or where the device does not connect with the train early enough for speed management to be viable, the device should revert to the field of safe travel interface.

• That further testing and refinement of interfaces is conducted, comparing different designs, to determine the most optimum configuration.

• That representatives from rail agencies take the lead to engage with road-based ITS committees, standards bodies and developers to ensure that the integration of RLX information into systems is achieved in line with good practice human factors principles.

• That road and rail agencies monitor new technological developments and consider extending ITS warnings beyond in-vehicle warnings to include applications that may be used by other types of road users (e.g. smartphones, smart watches and other wearable technologies).
Recommendations for changes to RLXs in urban environments

The following recommendations are made for changes to RLXs in urban environments:

- Consideration of traffic lights as an additional control at higher risk active urban RLXs.
- Trialling of pedestrian shelters with ticketing machines where the RLX is adjacent to a station.
- Trialling of RLX attendants at high risk locations during peak times, potentially utilising existing staff such as customer service officers.
- Addition of separated bicycle lanes in RLX upgrades.
- Trialling of shared space designs, using the raised ramp area with existing RLX controls (boom barriers, flashing lights, audible warnings), at specific urban locations adjacent to busy stations.

Recommendations for changes to RLXs in rural environments

The following recommendations are made for changes to RLXs in rural environments:

- Trialling of road markings to emphasise the ‘danger zone’ across the RLX.
- Further investigation into the use of mirrors at RLXs including whether they can be practically implemented and to ensure that the design will not introduce new human factors risks.
- Further investigation / field trials of improved train conspicuity, particularly focusing on drawing attention to the front of the train.

Recommendations for RLX management

The following recommendations are made to support the continuous improvement of safety at RLXs:

- **Data:** Continue efforts to increase the scope of data collection to include normal performance at RLXs, rather than collection of near miss and collision data only. This can provide real-time risk information for decision making and intervention, but will require the commitment of long-term funding to achieve.
- **Standards:** That engineering standards for RLX design promote a process that is more focused on risk management in the context of individual crossings rather than achieving consistency without reference to local conditions. Risk assessment should be conducted on a site by site basis involving appropriate experts and stakeholders (including human factors, engineering, road user representatives) and should identify solutions appropriate to the context. Where possible, data on road user behavior should be used to inform re-design.
- **Integration of systems thinking:** That consideration is given to determining how the findings from the systems analyses can be used to input to and improve the models and approaches used by RLX stakeholder agencies in Australia (e.g. ALCAM, evaluation processes for new technologies, investigation methodologies and data collection tools).
- **Shared responsibility:** That RLX stakeholders continue to build a culture of shared responsibility for RLX safety through the implementation of appropriate performance measures and incentives on all agencies around reducing risk. In addition, that stakeholders look for opportunities to combine safety goals with other priorities (e.g. community building) to gain traction.

Concluding remarks

The culmination of the research program provides a watershed moment within transportation safety worldwide as it represents the first attempt at implementing systems thinking and sociotechnical systems theory throughout the transport design lifecycle. The findings have a number of implications for RLX safety and indeed transportation safety generally.
REFERENCES


## Publications on RLX safety

### Journal papers

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<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Abstract</th>
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<tr>
<td>Beanland, V., Lenné, M. G., Salmon, P. M., &amp; Stanton, N. A. (2016).</td>
<td>Variability in decision-making and critical cue use by different road users at rail level crossings. <em>Ergonomics, 59</em>(6), 754-766.</td>
<td>Collisions at rail level crossings (RLXs) are typically high-severity and high-cost, often involving serious injuries, fatalities and major disruptions to the transport network. Most research examining behaviour at RLXs has focused exclusively on drivers and consequently there is little knowledge on how other road users make decisions at RLXs. We collected drivers', motorcyclists', bicyclists' and pedestrians' self-reported daily experiences at RLXs for two weeks, focusing on behaviour, decision-making and information use in the presence of a train and/or activated RLX signals. Both information use and behaviour differed between road users. Visual information (e.g. flashing lights) was more influential for motorists, whereas pedestrians and cyclists relied more on auditory information (e.g. bells). Pedestrians were also more likely to violate active RLX warnings and/or cross before an approaching train. These results emphasise the importance of adopting holistic RLX design approaches that support cognition and behaviour across for all road users.</td>
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<tr>
<td>Mulvihill, C., Salmon, P. M., Beanland, V., Lenné, M. G., Read, G. J. M., Walker, G. H., &amp; Stanton, N. A. (2016).</td>
<td>Using the decision ladder to understand road user decision making at actively controlled rail level crossings. <em>Applied Ergonomics, 56</em>, 1–10.</td>
<td>Rail level crossings (RLXs) represent a key strategic risk for railways worldwide. Despite enforcement and engineering countermeasures, user behaviour at RLXs can often confound expectations and erode safety. Research in this area is limited by a relative absence of insights into actual decision making processes and a focus on only a subset of road user types. One-hundred and sixty-six road users (drivers, motorcyclists, cyclists and pedestrians) completed a diary entry for each of 457 naturalistic encounters with RLXs when a train was approaching. The final eligible sample comprised 94 participants and 248 encounters at actively controlled crossings where a violation of the active warnings was possible. The diary incorporated Critical Decision Method probe questions, which enabled user responses to be mapped onto Rasmussen’s decision ladder. Twelve percent of crossing events were non-compliant. The underlying decision making was compared to compliant events and a reference decision model to reveal important differences in the structure and type of decision making within and between road user groups. The findings show that engineering countermeasures intended to improve decision making (e.g. flashing lights), may have the opposite effect for some users because the system permits a high level of flexibility for circumvention. Non-motorised users were more likely to access information outside of the warning signals because of their ability to achieve greater proximity to the train tracks and the train itself. The major conundrum in resolving these issues is whether to restrict the amount of time and information available to users so that it cannot be used for circumventing the system or provide more information to help users make safe decisions.</td>
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| Read, G. J. M., Salmon, P. M., Lenné, M. G. (2013). | Sounding the warning bells: the need for a systems approach to rail level crossing safety. *Applied Ergonomics, 44*, 764-774. | Collisions at rail level crossings are an international safety concern and have been the subject of considerable research effort. Modern human factors practice advocates a systems approach to investigating safety issues in complex systems. This paper describes the results of a structured review of the level crossing literature to determine the extent to which a systems approach has been applied. The measures used to determine if previous research was underpinned by a systems approach were: the type of analysis method utilised, the number of component relationships considered, the number of user groups considered, the number of system levels considered and the type of model described in the research. None of research reviewed

**Abstract:** The Cognitive Work Analysis Design Toolkit (CWA-DT) is a recently developed approach that provides guidance and tools to assist in applying the outputs of CWA to design processes to incorporate the values and principles of sociotechnical systems theory. In this paper, the CWA-DT is evaluated based on an application to improve safety at rail level crossings. The evaluation considered the extent to which the CWA-DT met pre-defined methodological criteria and aligned with sociotechnical values and principles. Both process and outcome measures were taken based on the ratings of workshop participants and human factors experts. Overall, workshop participants were positive about the process and indicated that it met the methodological criteria and sociotechnical values. However, expert ratings suggested that the CWA-DT achieved only limited success in producing RLX designs that fully aligned with the sociotechnical approach. Discussion about the appropriateness of the sociotechnical approach in a public safety context is provided.


**Abstract:** Pedestrian fatalities at rail level crossings (RLXs) are a public safety concern for governments worldwide. There is little literature examining pedestrian behaviour at RLXs and no previous studies have adopted a formative approach to understanding behaviour in this context. In this article, cognitive work analysis is applied to understand the constraints that shape pedestrian behaviour at RLXs in Melbourne, Australia. The five phases of cognitive work analysis were developed using data gathered via document analysis, behavioural observation, walk-throughs and critical decision method interviews. The analysis demonstrates the complex nature of pedestrian decision making at RLXs and the findings are synthesised to provide a model illustrating the influences on pedestrian decision making in this context (i.e. time, effort and social pressures). Further, the CWA outputs are used to inform an analysis of the risks to safety associated with pedestrian behaviour at RLXs and the identification of potential interventions to reduce risk.


**Abstract:** Accidents at rail level crossings (RLXs) represent an important public safety concern. Traditional approaches to RLX safety have focused on the implementation of technology such as warnings and barriers to control road user behaviour. However, as RLXs are complex sociotechnical systems, there is a need to apply systems-based approaches to analysis and design within this domain. This will enable road and rail stakeholders to develop innovative design solutions which are appropriate for the complexity of the domain, including adaptability to future changes in a dynamic transport environment. This paper describes the use of one aspect of a systems thinking-based design toolkit to prompt design insights following the application of the cognitive work analysis framework to RLXs. The process resulted in the identification of design insights for use in a participatory design process and supported the research team to consider the principles of sociotechnical systems theory.

Salmon, P. M., Lenné, M. G., Read, G. J. M., Mulvihill, C., Young, K., Cornelissen, M., Walker, G. H., & Stanton, N. A. (2016). More than meets the eye: using cognitive work analysis to identify design requirements for safer rail level crossing systems was found to be consistent with a systems approach. It is recommended that further research utilise a systems approach to the study of the level crossing system to enable the identification of effective design improvements.

Abstract: Overall the analysis identified a range of instances where modification or redesign in line with systems thinking could potentially improve behaviour and safety. A notable finding is that there are opportunities for redesign outside of the physical rail level crossing infrastructure, including improved data systems, in-vehicle warnings and modifications to design processes, standards and guidelines. The implications for future rail level crossing systems are discussed.


Abstract: Crashes between cars and trains at rail level crossings are problematic worldwide. Despite this, key facets of driver behaviour at rail level crossings, such as situation awareness and decision making, remain ambiguous. This is largely down to the inability of existing methodologies to describe or evaluate the cognitive aspects of driver behaviour when negotiating rail level crossings. This paper showcases an on-road approach for examining driver situation awareness at rail level crossings. The study presented involved participants, classified either as novice or experienced drivers, providing concurrent verbal protocols as they drove a pre-determined urban route incorporating four rail level crossings. Driver situation awareness was modelled using a network analysis-based approach and the structure and content of the networks was assessed. The analysis revealed key differences between novice and experienced drivers situation awareness at rail level crossings. In closing, the benefits of the on-road approach are discussed and a series of wider driver behaviour applications are proposed.


Abstract: In 2007 a loaded semi-trailer truck struck a passenger train on a railway level crossing in Northern Victoria, Australia, killing eleven train passengers. Although the incident was formally investigated, why the truck driver proceeded through the crossing in the presence of a train remains unexplained. This article uses two juxtaposed Human Factors approaches to provide insight into the contributory factors underlying the incident. A systems analysis framework is used to examine the rail level crossing system in which the incident occurred and an individual psychological schema theory account is used to examine the failures which led the truck driver to proceed through the crossing in the presence of a train. The findings suggest that the primary cause of the incident was a looked-but-failed-to-see error driven by a faulty activation of schema error, leading the truck driver to assume initially that the crossing was in fact in a non-activated state with no train present. Moreover, various system-wide factors that shaped the rail level crossing ‘system’ and thus the incident are identified.


Abstract: Crashes at rail level crossings (RLXs) remain a persistent but ill-defined safety issue. In urban areas, RLXs are typically located in areas of high workload and visual clutter, such as busy shopping strips. Despite this, the impact of such environments on driver behaviour and compliance with RLX controls is not well understood. This study sought to examine where drivers direct their attention on approach to urban RLXs located in busy shopping strip areas, and whether this differs between novice and experienced drivers. Participants drove an instrumented vehicle around a pre-defined urban route containing several active (flashing light with boom barriers) RLXs. Drivers’ visual scanning behaviour and cognitive processes were examined on approach to RLXs. The results suggest that RLXs were not a key focus of drivers’ attention. Further, rather than actively scanning, participants were over-reliant on RLX warning signals and the behaviour of surrounding vehicles to alert them to the presence of both trains and RLXs. This study provides important insights into drivers’ visual and cognitive behaviour on approach to urban RLXs located in areas of high visual demand.
<table>
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<th>Conference papers</th>
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<tr>
<td>Beanland, V., Lenné, M. G., Salmon, P. M., &amp; Stanton, N. A. (2013). A self-report study of factors influencing decision-making at rail level crossings: Comparing car drivers, motorcyclists, cyclists and pedestrians. In: Proceedings of the 2013 Australasian Road Safety Research, Policing &amp; Education Conference (11 pp.). Canberra, Australia: Australasian College of Road Safety.</td>
<td><strong>Abstract:</strong> Collisions at rail level crossings (RLXs) represent a major challenge for both road safety and rail safety professionals. RLX collisions are typically high-severity and high-cost, often involving multiple injuries and/or fatalities as well as major disruptions to the transportation network. Most research examining road users’ behaviour at RLXs has focused exclusively on drivers and consequently there is little existing knowledge on how other road users make decisions at RLXs. We designed a longitudinal survey to prospectively record interactions at RLXs over a two-week period. The sample included 166 adults residing in metropolitan Melbourne (80%) and regional Victoria (20%), with a mix of car drivers, motorcyclists, bicyclists and pedestrians. Respondents completed the survey daily and provided a detailed account of any encounters with trains and/or activated RLX warnings, with the survey prompts based on a cognitive task analysis methodology. The results reveal that both experiences and behaviour at RLXs differ substantially across different road users. Visual information (e.g., flashing lights) emerged as one of the most influential factors for car drivers and motorcyclists, whereas pedestrians and to a lesser extent cyclists relied more on auditory information (e.g., bells) to alert them to the presence of a train. Pedestrians were also more likely than other road users to speed up and cross the tracks ahead of an approaching train. Overall these results emphasise the importance of designing road systems to support cognition and behaviour across a range of road users, in order to ensure a safe system for all.</td>
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<tr>
<td>Lenné, M. G., Salmon, P. M., Beanland, V., Stanton, N. A., &amp; Filtness, A. (2013). On-road driving studies to understand why drivers behave as they do at regional rail level crossings. In: Proceedings of the 2013 Australasian Road Safety Research, Policing &amp; Education Conference (7 pp.). Canberra, Australia: Australasian College of Road Safety.</td>
<td><strong>Abstract:</strong> Improving safety at rail level crossings is an important part of both road and rail safety strategies. While low in number, crashes between vehicles and trains at level crossings are catastrophic events typically involving multiple fatalities and serious injuries. Advances in driving assessment methods, such as the provision of on-road instrumented test vehicles with eye and head tracking, provide researchers with the opportunity to further understand driver behaviour at such crossings in ways not previously possible. This paper describes a study conducted to further understand the factors that shape driver behaviour at rail level crossings using instrumented vehicles. Twenty-two participants drove an On-Road Test Vehicle (ORTeV) on a predefined route in regional Victoria with a mix of both active (flashing lights with/without boom barriers) and passively controlled (stop, give way) crossings. Data collected included driving performance data, head checks, and interview data to capture driver strategies. The data from an integrated suite of methods demonstrated clearly how behaviour differs at active and passive level crossings, particularly for inexperienced drivers. For example, the head check data clearly show the reliance and expectancies of inexperienced drivers for active warnings even when approaching passively controlled crossings. These studies provide very novel and unique insights into how level crossing design and warnings shape driver behaviour.</td>
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<tr>
<td>Lenné, M. G., Salmon, P. M., Stanton, N. A., &amp; Grey, E. (2013). Actualising a safe transport system through a human factors systems approach. In Proceedings of the 15th International Conference on Human-Computer Interaction, 21 - 26 July 2013. Las Vegas, USA.</td>
<td><strong>Abstract:</strong> Safe system strategies govern the approaches to road safety in many countries. This is the case for both road and rail safety in Australia. In this paper we take a complex segment of the road and rail system, rail level crossings, to demonstrate why the current approaches to safety in this area need to change. We argue that approaches that are more consistent with real systems thinking are required to generate the new interventions needed to reduce road trauma in this setting. In recognizing the need for new approaches the Victorian road and rail sponsors have partnered with Australian and UK Universities in an exciting four year initiative designed to change the paradigm in RLX safety. In this paper we outline the rationale for this change and describe the four phase analytical approach being used. It is hoped that this approach will help to actualise safe system strategies in ways</td>
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**Abstract:** Collisions at rail level crossings (RLXs) present an ongoing major challenge for both road and rail safety organisations. Previous research has made little systematic attempt to understand road user decision making at RLXs, with most research relying on observational studies of single road user groups only. In this exploratory study, we applied Rasmussen’s (1974) decision ladder (DL) for the first time in the RLX safety context to compare the decision making processes used during compliant and non-compliant encounters at RLXs. The data used to populate the DL was derived from a two-week diary study in which four groups of road users (drivers, motorcyclists, cyclists and pedestrians) described their encounters with actively controlled RLXs when a train was approaching. Ninety-five road users made a total of 247 crossings, 11.7 % of which were non-compliant (n = 29). Overall, the decision making processes differed between compliant and non-compliant encounters. On non-compliant encounters road users were least concerned with safety, based their decision making on a much smaller component of the RLX system, and proceeded further along the DL (i.e., considered multiple courses of action). The results of this study may have important implications for RLX designs, but firstly should be validated using larger samples of non-compliant encounters.


**Abstract:** Level crossings represent one of the key strategic risks on railways across the world. Recent research has indicated that collisions at rail level crossings (RLXs) may be better prevented through more sophisticated allocation of functions within these environments. The aim of the research described here was to explore this further and to identify potential design remedies. Cognitive Work Analysis (CWA) is a systems analysis framework that has been successfully used to identify how social and technical components within systems can be configured to enhance overall performance. Two CWA techniques were used to identify design options related to how functions are allocated within RLX systems. Based on an analysis of nine RLXs in metropolitan Melbourne, the findings highlighted an uneven spread of activity across the situations in which train detection and safety can occur and across the actors involved in these functions. The majority of activity currently occurs when users are closest to the RLX. However, there are instances where important activities could occur away from the RLX but typically do not. In addition, the analysis showed that the RLX infrastructure is currently responsible for most functions relating to safety, and there are parts of the system that could be better exploited to support and/or improve behaviour, including humans, in-vehicle systems and the surrounding infrastructure.


**Abstract:** Rail level crossings (RLXs) are a public safety concern internationally. The design of the RLX environment has been implicated in many recent crashes. In this study we evaluated three novel RLX design concepts using a driving simulator. Participants completed four drives, each incorporating one of the RLX designs (one baseline and three novel designs) in both train coming and train not coming mode. Measures of speed and braking on approach were analyzed, along with subjective measures of workload and usability. Superior driving behavior and subjective ratings were achieved for a design that incorporated an in-vehicle device while the lowest subjective ratings were given in relation to a shared space design that incorporated a simplified crossing environment and sharing of the road environment between motorized and non-motorized users. The implications for RLX safety are discussed.
<table>
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<tr>
<th>Read, G. J. M., Salmon, P. M. &amp; Lenné, M. G. (2015). An explorative analysis of pedestrian situation awareness at rail level crossings. Proceedings of the Australasian Road Safety Conference, Gold Coast, October 2015.</th>
<th><strong>Abstract:</strong> Pedestrian safety at rail level crossings (RLXs) is a concern for governments and the community. There is sparse published literature, however, that has investigated pedestrian situation awareness when negotiating RLXs. This paper presents the findings from an exploratory study of pedestrian situation awareness at RLXs. Fifteen participants took part in a naturalistic study in which participants walked a pre-defined route in one of three urban environments, each of which incorporated two RLXs. Whilst walking the route participants wore video recording glasses and provided 'think aloud' verbal protocols describing the cognitive processes and decision making underpinning their behaviour. Analysis of the verbal protocols provided during the approach and traversal of the RLX was conducted using content analysis software as well as through manual analysis of the data. The analysis identified that pedestrian situation awareness was most commonly underpinned by concepts such as the 'railway crossing', the 'train' and other 'pedestrians'. Interestingly, concepts such as 'bells', 'flashing lights' and the 'pedestrian gate' were not prominent. This may reflect that most participants did not encounter the RLX when a train was approaching. However, concepts around checking for the train were prominent suggesting that many pedestrians may not simply rely on automatic warnings, but use their own judgement to make a decision about when it is safe to cross a RLX. Further findings, implications for RLX design, limitations and future research directions will be discussed.</th>
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<tr>
<td>Read, G. J. M., Salmon, P. M. &amp; Lenné, M. G. (2015). Using cognitive work analysis and the sociotechnical systems approach to improve pedestrian safety at rail level crossings. Proceedings 19th Triennial Congress of the IEA, Melbourne, 9-14 August 2015.</td>
<td><strong>Abstract:</strong> The sociotechnical systems approach argues that systems with adaptive capacity will be safer. However, this approach may conflict with current practice in safety management. We applied cognitive work analysis to understand the problem of pedestrian safety at rail level crossings and used the findings to evaluate the current design against the values of sociotechnical systems theory. The evaluation was conducted against indicators developed based on the sociotechnical literature and it is concluded that the existing design of rail level crossings does not align with the values. Recommendations for improving the design of rail level crossings are identified and discussed.</td>
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<td>Read, G. J. M., Salmon, P. M., Lenné, M. G. &amp; Grey, E. M. (2014). Evaluating design hypotheses for rail level crossings: An observational study of pedestrian and cyclist behaviour. Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics, Kraków, Poland.</td>
<td><strong>Abstract:</strong> Accidents involving pedestrians at rail level crossings are a significant public safety concern in Australia and internationally. The current design of rail crossings incorporates assumptions and hypotheses about how people will interact with the infrastructure at the crossing. The hypotheses associated with the design of pedestrian rail crossings in metropolitan Melbourne were evaluated through the findings of naturalistic observations of users. Comparison of actual behavior as recorded in the observations was compared to the design hypotheses relating to the features at the crossing. While for some the majority of behavior was in line with the hypothesis, it was found that a number of the hypotheses were not always supported. The evaluation uncovered unexpected interactions between users and the infrastructure, as well as implications for rail crossing design. The findings support the need for a systems approach to the analysis and design of rail crossings from a pedestrian and cyclist safety perspective to assist understanding of the system and to inform its re-design.</td>
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<tr>
<td>Salmon, P. M., Lenné, M. G., Beanland, V., Young, K. L., Filtness, A., Stanton, N. A., &amp; Read, G. J. M. (2014). From the Bush to the Burbs: an on-road study of driver situation awareness at rural and urban railway level crossings.</td>
<td><strong>Abstract:</strong> The problem of collisions between road users and trains at rail level crossings (RLXs) remains resistant to current countermeasures. One factor underpinning these collisions is poor Situation Awareness (SA) on behalf of the road user involved (i.e. not being aware of an approaching train). Although this is a potential threat at any RLX, the factors influencing SA may differ depending on whether the RLX is located in a rural or urban road environment. Despite this, there has been no empirical investigation regarding how road user SA might differ across distinct RLX environments.</td>
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<td>Salmon, P. M., Lenné, M. G., Read, G. J. M., Mulvihill, C. M., Cornelissen, M., Young, K. L., Walker, G. H., Stanton, N. A. &amp; Stevens, N. (2015).</td>
<td>Abstract: Progress is not being made on the longstanding problem of collisions between people and trains at rail level crossings. It has been suggested that this may be, in part, due to a lack of systems thinking during design, crash analysis, and countermeasure development. This paper presents a systems analysis of current rail level crossing systems in Australia that was undertaken specifically to identify safety-related issues in rail level crossing environments. Cognitive work analysis was used to analyze current rail level crossing systems based on data derived from a range of focused data collection activities. The analysis identified various issues potentially impacting behavior and safety across the different users of rail level crossings. In addition, potential areas for improvement through redesign were highlighted. An important implication of the study is that improvements in behavior and safety may be achievable through changes to the overall rail level crossing system (e.g., values, goals, norms, data systems) as opposed to changes to the physical rail level crossing infrastructure only. The implications for future rail level crossing design activities are discussed.</td>
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<td>Salmon, P. M., Lenné, M. G., Young, K. L., Tomasevic, N., Williamson, A., &amp; Rudin-Brown, C. M. (2010).</td>
<td>Abstract: Crashes at rail level crossings represent a significant problem, both in Australia and worldwide. Advances in driving assessment methods, such as the provision of on-road instrumented test vehicles, now provide researchers with the opportunity to further understand driver behaviour at rail level crossings in ways not previously possible. This paper gives an overview of a recent on-road pilot study of driver behaviour at rail level crossings in which 25 participants drove a pre-determined route, incorporating 4 rail level crossings, using MUARC’s instrumented On-Road Test Vehicle (ORTeV). Drivers provided verbal commentary whilst driving the route, and a range of other data were collected, including eye fixations, forward, cockpit and driver video, and vehicle data (speed, braking, steering wheel angle, lane tracking etc.). Participants also completed a post trial cognitive task analysis interview. Extracts from the wider analyses are used to examine in depth driver behaviour at one of the rail level crossings encountered during the study. The analysis presented, along with the overall analysis undertaken, gives insight into the driver and wider systems factors that shape behaviour at rail level crossings, and highlights the utility of using a multi-method, instrumented vehicle approach for gathering data regarding driver behaviour in different contexts.</td>
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| Salmon, P. M., Lenné, M. G., Young, K. L. & Walker, G. H. (2011). | Abstract: Poor or degraded situation awareness has previously been identified as a contributory factor in crashes at rail level crossings. Despite this, the concept remains largely unexplored in this context. This paper describes an exploratory on-road study focusing on novice and experienced driver situation awareness whilst negotiating rail level crossings. Participants drove a pre-determined urban route, incorporating two rail level crossings, in an instrumented vehicle. Situation awareness was assessed using propositional networks which were constructed based on content analyses of driver verbal protocols. Differences between drivers’ situation awareness were found in terms of the information underpinning it and the integration of this information. It is concluded that, whilst negotiating the two rail level crossings, inexperienced drivers had less efficient situation awareness than

Abstract: There is growing consensus that increased understanding of, and reductions in, road trauma, can be achieved through a systems theory driven approach to road safety. To test this assertion, this paper presents an application of three contemporary systems analysis methods in the road and rail transport context: Accimap, Cognitive Work Analysis and STAMP. The methods were used to describe the Kerang tragedy in which a loaded semi-trailer truck struck a passenger train on a railway level crossing in Northern Victoria, Australia, killing eleven train passengers. The analyses indicate that a more exhaustive insight into the causes of road trauma can be achieved through the application of such methods. Notable outcomes include that the role of factors beyond road users (e.g. government, road rules, road designers) in road trauma is elucidated, that issues influencing road system efficiency are identified, and that countermeasures derived from this approach are likely to be more holistic, treating conditions across the entire transportation system.


Abstract: The continued incidence of trauma at rail level crossings is unacceptable, and provides a clear indication that the current approach to rail level crossing safety is failing. It has been suggested that this may be, in part, attributed to the fact that a systems thinking approach has not been adopted when attempting to improve rail level crossing designs. As a response, this paper presents an overview of a rail level crossing design lifecycle process that involved applying Cognitive Work Analysis to analyze existing rail level crossing systems, and then to generate, evaluate, and refine new rail level crossing design concepts underpinned by systems thinking. An overview of the process adopted is provided and selected outputs from the following phases are discussed: systems analysis; generation of design concepts, evaluation of design concepts, and refinement of design concepts. In closing, the implications for future rail level crossing design activities are discussed.

**Book chapters**


Abstract: Crashes between vehicles and trains at highway-rail grade crossings are low in number but are catastrophic events typically involving multiple fatalities and serious injuries. Advances in driving assessment methods, such as the development of on-road instrumented test vehicles, now enable researchers to understand driver behaviour at such crossings in ways not previously possible. This paper describes a study conducted to explore factors that shape driver behaviour at rail level crossings using instrumented vehicles in metropolitan and regional locations. Twenty-two participants drove an On-Road Test Vehicle (ORTeV) on a predefined route in rural Australia with a mix of both active (flashing lights with/without boom barriers) and passively controlled (stop, give way) crossings. Data collected included driving performance data, head checks, and post-drive interviews to capture driver strategies. While the focus in this paper is on the head check data, the data from the full suite of integrated methods clearly demonstrated how behaviour differs at active and passive level crossings, particularly for novice drivers. For example, head check data show the reliance and expectancies of novice drivers for active warnings even when approaching passively controlled crossings. These studies provide novel and unique insights into how level crossing design and warnings shape driver behaviour.

Salmon, P. M., Beanland, V. Lenné, M. G., Filtness, A., Stanton, N. A. (2013). Waiting for warning? Driver Abstract: Driver behaviour at rail level crossings represents a key area for further research. This paper describes an on-road study comparing novice and experienced driver situation awareness at rural rail level crossings. Participants provided verbal protocols while driving a pre-determined rural...


No abstract available.

Publications on CWA

### Journal papers

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<th>Author(s)</th>
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<td>Read, G. J. M., Salmon, P. M., Lenné, M. G., &amp; Stanton, N. A. (2015).</td>
<td>Designing sociotechnical systems with cognitive work analysis: Putting theory back into practice. <em>Ergonomics, 58</em>(5), 822-851.</td>
<td>Cognitive work analysis (CWA) is a framework of methods for analysing complex sociotechnical systems. However, the translation from the outputs of CWA to design is not straightforward. Sociotechnical systems theory provides values and principles for the design of sociotechnical systems which may offer a theoretically consistent basis for a design approach for use with CWA. This article explores the extent to which CWA and sociotechnical systems theory offer complementary perspectives and presents an abstraction hierarchy (AH), based on a review of literature, that describes an ‘optimal’ CWA and sociotechnical systems theory design system. The optimal AH is used to assess the extent to which current CWA-based design practices, uncovered through a survey of CWA practitioners, aligns with sociotechnical systems theory. Recommendations for a design approach that would support the integration of CWA and sociotechnical systems theory design values and principles are also derived.</td>
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<td>Read, G. J. M., Salmon, P. M., &amp; Lenné, M. G. (2015).</td>
<td>Cognitive work analysis and design: Current practice and future practitioner requirements. <em>Theoretical Issues in Ergonomics Science, 16</em>(2), 154-173.</td>
<td>Cognitive work analysis (CWA) is a unique analytical framework which provides analysis information to inform system design. However, the literature describing CWA applications indicates that its use in design is not straightforward. An online survey was used to gather information from CWA practitioners about how they have used CWA in design applications and to gather their views and attitudes on aspects of CWA and design. The survey found that there was no typical means of using the outputs of CWA within design processes across survey respondents. Over half of the respondents indicated that there is a need for an additional approach or method to enhance the contribution of CWA to design. It is concluded that the field could benefit from the development of an additional design approach, with</td>
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associated guidance, to assist in using the outputs of CWA in design processes.


Abstract: Cognitive work analysis has been applied in the design of numerous sociotechnical systems. The process used to translate analysis outputs into design concepts, however, is not always clear. Moreover, structured processes for translating the outputs of ergonomics methods into concrete designs are lacking. This paper introduces the Cognitive Work Analysis Design Toolkit (CWA-DT), a design approach which has been developed specifically to provide a structured means of incorporating cognitive work analysis outputs in design using design principles and values derived from sociotechnical systems theory. This paper outlines the CWA-DT and describes its application in a public transport ticketing design case study. Qualitative and quantitative evaluations of the process provide promising early evidence that the toolkit fulfils the evaluation criteria identified for its success, with opportunities for improvement also highlighted.

Conference papers


Abstract: Analysis and design activities underpinned by the systems thinking are required for the design of modern complex sociotechnical systems. Cognitive work analysis is a commonly used analysis framework for understanding complex systems. Although the framework was developed with a view to then using analysis outputs to inform system design, questions about its direct application to design remain. This paper will describe an approach that was developed to support the translation of cognitive work analysis outputs into design-relevant information. The approach was applied to a case study analysis of a public transport ticketing system, with the insights documented during the analysis being used to prepare design materials for a participatory design workshop. The process of identifying design-relevant information from the analysis outputs and applying this to the preparation of design materials was found to be structured and efficient, providing the potential for traceability between analysis and design without constraining the creativity required for design innovation.


Abstract: Cognitive work analysis is a framework for analysis to inform the design of complex cognitive systems. However, the framework has been criticized for failing to directly inform design. This paper describes a review of CWA design applications and analyses the way in which CWA-based designs have been developed. The review reveals that the majority of CWA-based design applications are associated with interface design. Further, when designing for causal, compared to intentional domains, CWA has more commonly been applied directly, with little use of further supplemental design methods or processes. In closing, the implications for augmenting CWA to support system design are discussed.