



6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the  
Affiliated Conferences, AHFE 2015

## Beyond the crossing: a cognitive work analysis of rail level crossing systems

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### 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.

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Peer-review under responsibility of AHFE Conference

**Keywords:** Situation awareness; Road intersections; Design; Cognitive work analysis; Event analysis of systemic teamwork; Schema theory

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## 1. Introduction

The problem of collisions between people and trains at rail level crossings remains a persistent road and rail safety issue. Regardless of jurisdiction, the statistics paint an unacceptable picture. In Australia, where the research presented in this paper was undertaken, there is little evidence of progress being made. For example, between 2000 and 2009 close to 100 fatalities were caused by collisions between road vehicles and trains at rail level crossings [1]. For pedestrians, the data shows that there were 92 collisions between trains and pedestrians at RLXs between 2002 and 2012 [2]. There is no doubt that rail level crossings represent a key issue for road and rail safety researchers and practitioners. Indeed, the continued incidence of trauma at rail level crossings is unacceptable, and provides a stark warning that the current approach to rail level crossing safety is failing. A new approach is needed.

This article describes part of a major program of research that is underpinned by the argument that rail level crossings continue to kill and injure their users because the appropriate approach has not been adopted when attempting to improve safety and behavior. Specifically, it is argued that a systems thinking approach has not been adopted when attempting to understand and improve rail level crossing safety [3, 4, 5]. Instead, the majority of research and practice has been reductionist, focusing on components in isolation (such as road users or rail level crossing warnings), which in turn has led to incremental design changes with only marginal impacts on behavior and safety. Reductionist approaches do not allow us to detect the emergent properties associated with collisions and are now widely accepted to be limited for safety management. Further, it has been argued that they are inappropriate within transportation systems such as road and rail [6]. It is the view of the authors that reductionist approaches have achieved all that they can in areas such as road and rail. The aim of the overall program of research is to respond to the repeated calls for a systems thinking approach to rail level crossing safety [3] by evaluating and redesigning them using systems analysis and design approaches.

A systems approach has much to offer in the rail level crossing context [3]. A key gap in the literature is an in-depth understanding of the behavior of rail level crossing systems. In particular, there has been scant analysis of behavior at rail level crossings through a systems lens, considering all users, components, and the interactions between them [3]. As a result, the prevalent perspective is that the problem is primarily one of road users failing to comprehend warnings and the presence of an approaching train. In turn, solutions have generally centered on the addition of new warnings designed to better alert users to the presence of a train. Without an understanding of the overall system and how interactions lead to rail level crossing collisions it is not possible to propose appropriate safety interventions.

This paper is a response to this, presenting a summary of the findings from a Cognitive Work Analysis [CWA; 7] of rail level crossings in Victoria, Australia. The aim is to communicate the findings from each analysis phase and to identify areas in which new designs can potentially be used to improve safety in rail level crossing systems. Selected examples of the CWA are presented along with discussion of the key findings in relation to rail level crossing safety and potential design modifications.

## 2. Cognitive Work Analysis

CWA [7] is a systems analysis and design framework that has been subject to many analysis and design applications across the human factors problem space [8, 9, 10, 11, 12]. The framework itself comprises five separate analysis phases. In the present study the first four of these phases were used. A brief description of each of the phases employed is given below. For a full description of the framework the reader is referred to [7 or 13].

### 2.1. Work Domain Analysis

The first phase of CWA, Work Domain Analysis (WDA) is used to construct a model of the system under analysis that describes the system in terms of its objects, affordances, functions, values and priority measures, and functional purpose. The aim is to describe the purposes of the system and the constraints imposed on the actions of any actor performing activities within that system [7]. The abstraction hierarchy method is used to construct the WDA. An important feature is the use of means-ends links to show the relationships between objects, affordances, values and priority measures, and functions.

## 2.2. Control Task Analysis

The second phase, Control Task Analysis (ConTA), is used to analyze in detail the tasks undertaken to achieve the functions described in the WDA. In the analysis presented in this paper Rasmussen's decision ladder was used. The decision ladder provides an overview of the decision making process underpinning control tasks, incorporating the information, goals, options, and courses of action considered when making decisions.

## 2.3. Strategies Analysis

The strategies analysis phase is used to identify all of the different ways in which the control tasks can be undertaken. The Strategies Analysis Diagram [8] is a recently developed approach that can be used to identify strategies by tracing paths through the WDA based on the means-ends links between physical objects, affordances, and functions. A key feature of the strategies analysis phase is that it shows the range of strategies available for different users to complete tasks.

## 2.4. Social Organization and Co-operation Analysis (SOCA)

The SOCA phase examines how functions, tasks and strategies are allocated across human and non-human agents within the system (and indeed how they could be in new configurations). SOCA is flexible in that can be undertaken on each of the outputs from the first three CWA phases. For example, conducting SOCA on the WDA involves mapping human and non-human agents onto affordances (i.e. who or what achieves which affordances), functions (i.e. who or what performance which functions), values and priority measures (i.e. who or what contributes to the values and priority measures), and functional purposes (i.e. who or what contributes to which functional purposes).

The four phases described above were used to analyze the current rail level crossing system in Victoria, Australia. The aim of the analysis was to generate an in-depth analysis of current rail level crossing systems through the four CWA lenses. The analysis presented in this paper focuses on so-called 'active' rail level crossings. Active RLXs have both 'active' warning devices that provide a warning of an approaching train, such as flashing lights, boom gates and warning bells, along with 'passive' warnings that also provide a warning of the RLX itself (e.g. static signs and road markings).

## 3. Method

### 3.1. Data sources

A range of data was collected to support the CWA. This data was obtained through the following studies:

- *On-road studies of driver behavior.* Two on-road studies of driver behavior at rail level crossings were undertaken [see 15 and 16]. Both involved participants driving an instrumented vehicle around a pre-defined route incorporating rail level crossings whilst providing concurrent verbal protocols (i.e. think aloud protocols). This data provided a detailed description of drivers' cognitive processes and decision making when negotiating rail level crossings;
- *Cognitive task analysis interviews with drivers.* Following completion of the drive in both of the on-road studies described above, participants partook in a Critical Decision Method (CDM; Klein and Armstrong, 2004) cognitive task analysis interview. The focus of the interviews was decision making at two of the rail level crossings encountered during the drive. This data provided an in-depth description of driver decision making and the factors influencing whether drivers decided to stop or go at each crossing.
- *Diary study of road user behavior.* A diary study was undertaken to collect data around decision making when a train was present at rail level crossings. 144 participants, including drivers, pedestrians, cyclists, and motorcyclists completed a CDM-based questionnaire for every train that they encountered at a rail level crossing over a two week period. This data provided an in-depth description of driver, pedestrian, cyclist and motorcyclist

decision making and the factors influencing whether they decided to stop or go through the crossing when a train was approaching [see 17];

- *Train driver focus groups.* A focus group was held with two train drivers and one rail subject matter expert (SME) to gather information regarding train driver behavior at rail level crossings. This data provided an overview of train drivers behavior and decision making processes when approaching and negotiating rail level crossings;
- *In-cab familiarization.* Three researchers participated in train cab rides through urban and regional areas to gain familiarity with the train-driving task and to understand the train driver perspective on rail level crossings; and
- *Subject Matter Expert (SME) workshop.* An SME workshop involving 11 rail and road safety SMEs was conducted to review and refine the draft WDA output.

The data derived from the activities was used to inform development of each of the four CWA phases. This involved various analysts, all with experience in applying CWA in problem spaces. The analyses were undertaken using the CWA software tool [13] and involved the conduct of various analysis workshops whereby analysts would work collaboratively on each analysis phase.

#### 4. Results

Given space constraints, the main focus of this article is on discussing the findings derived from the CWA. Accordingly, only selected outputs are presented. A summary of the active rail level crossing WDA is presented in Figure 1.

An extract of the decision ladder for users’ stop or go decision at rail level crossings is presented in Figure 2. The decision ladder presented incorporates all of the data from the different users involved in the diary study (e.g. drivers, pedestrians, cyclists, and motorcyclists).

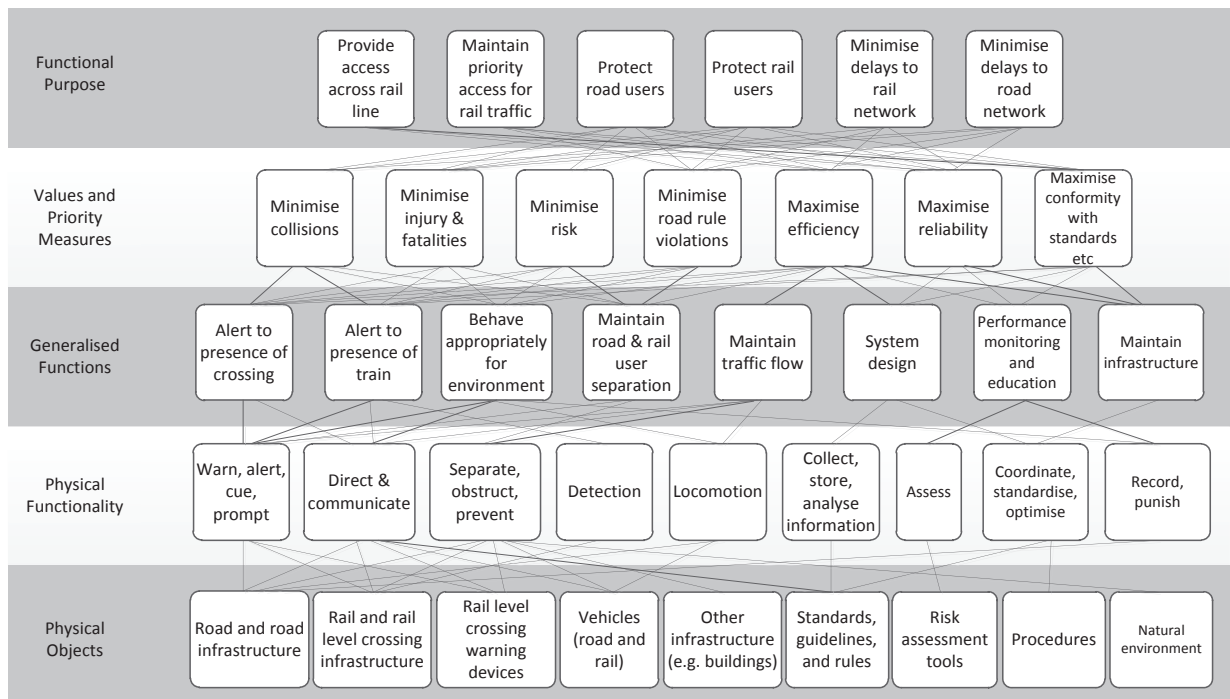


Fig. 1. Summary of active rail level crossing WDA [14].

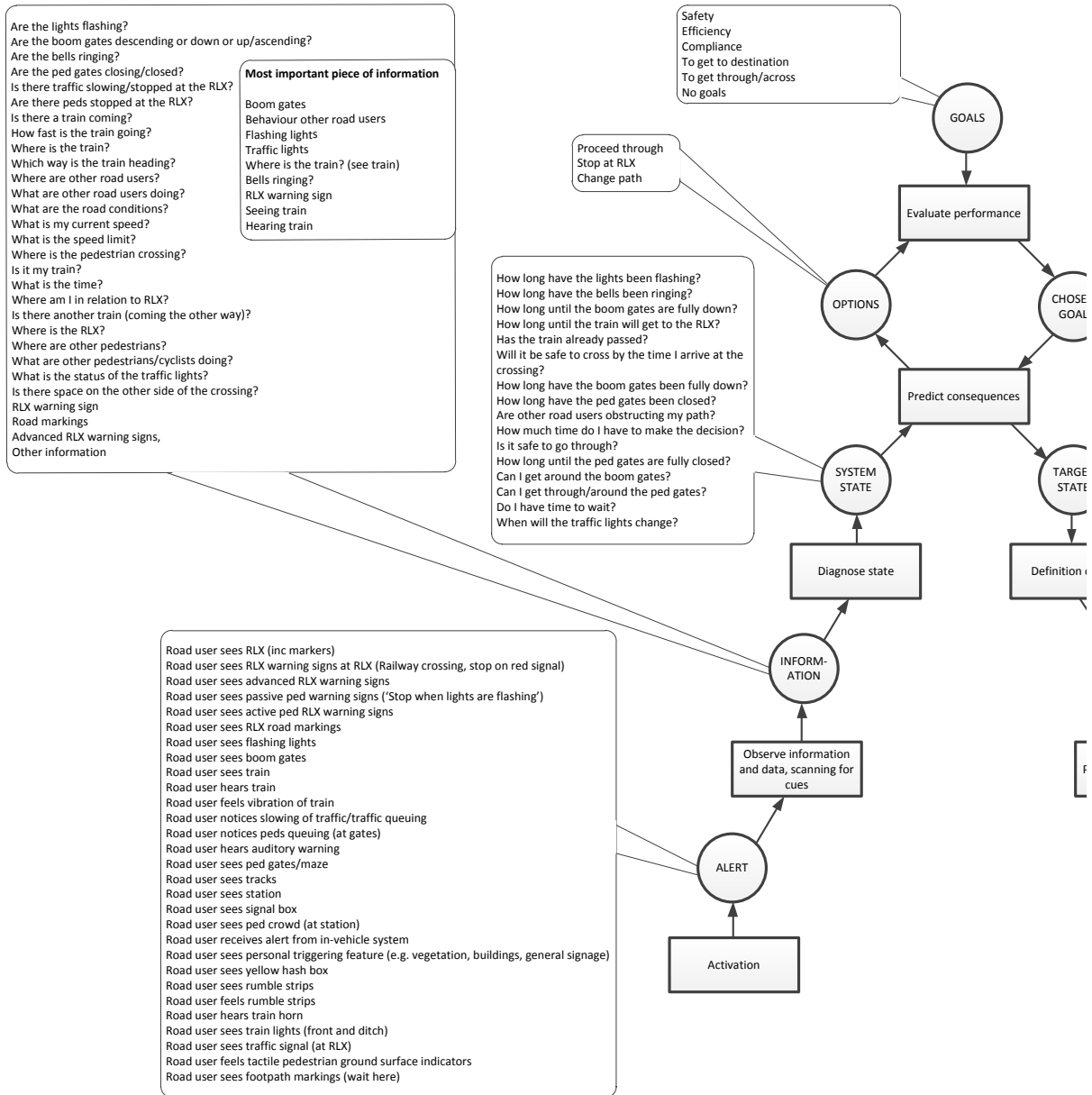


Fig. 2. Extract of decision ladder for stop and go decision at rail level crossings. Figure shows the left hand side of the decision ladder incorporating alert, information, system state, options, and goals [adapted from 14].

**5. Discussion**

A systems approach is needed to prevent collisions at rail level crossings. The aim of this article was to present and discuss a snapshot of the findings from a four phase CWA of rail level crossings in Victoria, Australia. This discussion focuses on the findings and some of their implications for improving behavior and safety at rail level crossings.

The CWA provides a rich description of how rail level crossing systems operate, how different users negotiate rail level crossings, and what constraints are imposed on users. This is useful, however the contribution of the analysis was that it identified many issues potentially impacting behavior and leading to unsafe outcomes. From the WDA it is clear that rail level crossing systems are complex environments, comprising many interacting components (human and non-human), multiple competing purposes, many values and priorities, and multiple pathways to failure. Whilst the full WDA provides an instant snapshot of this complexity, perhaps the most important implication is that modifications may be required across the wider rail level crossing system and not just at the rail level crossings themselves (e.g. addition of new, more conspicuous warnings). Indeed, many examples of potential wider systems reforms are hinted at. For example, an inability of the system currently to accurately monitor the extent to which values and priorities are being met (identified in the WDA) suggest that the introduction of new data collection and analysis systems, or at least improvement of existing systems, is required. In particular, improved incident and near miss reporting and analysis systems will enable stakeholders to generate a deeper and more accurate understanding of rail level crossing risks and performance. Whilst such systems do exist, different systems are often used by different stakeholders (e.g. rail service providers versus rail authorities) and there appears to be little sharing or communication of data. In addition, improved risk assessment systems will ensure that there is an appropriate understanding of the risks associated with different rail level crossings. Risk assessment represents an important function within the wider system; however, it is questionable whether this function is currently being adequately achieved. A final important finding from the WDA was the presence of competing functional purposes (e.g. safety versus efficiency); this represents a key issue impacting the development and implementation of new safety measures as interventions may improve safety but adversely impact efficiency. As a corollary there is often resistance around new interventions that might lead to trains passing through crossings at slower speeds (or even stopping) or longer delays at the crossing for on-road traffic. Resolving the tension between efficiency and safety at rail level crossings is a key line of further inquiry.

The decision ladder (ConTA) identified the range of information, goals, and courses of action available to rail level crossing users, which in turn emphasized the importance of considering how different user groups interact with rail level crossing infrastructure. The variability in behavior in terms of how users seek information and decide whether to cross or not is a striking conclusion here. The analysis showed that there are a range of different sources of information that road users and pedestrian use, first, to become aware that a rail level crossing is approaching and second, to inform their decision to stop or go at the crossing. Notably some were expected, such as signage, flashing lights, boom gates, and the train itself, whereas some were less so, such as the behavior of other road users (e.g. pedestrians and traffic queues) and personal triggering features such as vegetation or a house. The implication here is that adaptive humans will utilize other features of the environment to determine whether it is safe to go through rail level crossings; notably this often involves going beyond the information provided by warnings to determine if it is still safe to cross despite the activated warnings. In short, users negotiate rail level crossings in different ways that are not always intended or supported by designers. An important question then is the extent to which these other features can be relied upon and have any risks associated with them. A further important aspect of this performance variability is that differences not only exist across different groups (e.g. drivers versus cyclists) but within groups too. For example, pedestrians negotiate rail level crossings differently to one another depending on their own goals and motivations (e.g. safety versus efficiency). A clear design implication here is that designers need to consider the range of ways in which users might interact with the overall rail level crossing, rather than just the ways in which they want them to interact and how they think they will respond to warnings. Evaluation and refinement of design concepts should consider emergent behaviors as well as expected behaviors.

The strategies analysis confirmed the decision ladder analysis in that multiple strategies to negotiate the crossing were identified for each form of rail level crossing user. Important insights were gained through examining the information that was not available to support different strategies. For example, a key issue identified is a failure of current warnings to provide specific information regarding the approaching train. The information currently presented is mainly generic, notifying users only that a train is coming (e.g. barriers, flashing lights). The analysis suggests that further specific information could potentially better support decision making, such as time to arrival of the train, the number of trains approaching, and the amount of time that the user will be delayed at the crossing if they wait for the train to pass through. The implication here is that the provision of more useful information

regarding the approaching train and the consequences of adhering to the crossing warnings may reduce users' perceived need to cross when a train is approaching.

The SOCA showed the distribution of tasks and functions across humans, technologies and artefacts at the crossing. The analysis demonstrated that there is potentially scope to develop a more appropriate allocation of tasks and functions within rail level crossing environments. Specifically the analysis suggests that the crossing infrastructure itself is currently responsible for the majority of the functions relating to safety, and that there are parts of the rail level crossing system that could be doing more to support and/or improve behavior, such as vehicles and in-vehicle systems and the infrastructure surrounding rail level crossings. Another interesting finding was that there is currently a heavy reliance on technology, and that humans are largely underexploited. Finally, the introduction of artefacts outside of the rail level crossings themselves could be beneficial. For example, shelter and facilities for pedestrians close to rail level crossings may increase the likelihood that they will wait for a train to pass rather than attempt to cross and beat the train.

This paper has presented a snapshot of an exhaustive systems analysis of rail level crossings in Victoria, Australia. A key contribution is that the analysis has enabled the behavior of all users to be understood, as opposed to individual user groups alone (e.g. drivers). This is a key gap in the existing rail level crossing literature (Read et al, 2013). Another contribution is the identification of areas for improvement through redesign or the introduction of new technologies and/or artefacts. There are many implications for the design of rail level crossings and notably not all relate to adding new or improved warnings to the rail level crossing infrastructure. It is hoped that this systems level analysis will encourage the development and evaluation of designs that cater for all users, not just one user group alone. The next phase of this research program involves developing new rail level crossing design concepts based on the CWA outputs, following which the concepts will then be evaluated and refined using CWA. Outside of this research program, further systems analysis and design applications are encouraged, both in this problem space and in surface transportation generally. Whilst such analyses are emerging [e.g. 8], a key challenge moving forward is to embed systems analysis and design methodologies within sociotechnical system design processes [18].

## Acknowledgements

This research was funded through an Australian Research Council Linkage Grant (ARC, LP100200387) to the University of Sunshine Coast, Monash University, and the University of Southampton, in partnership with the following partner organizations: the Victorian Rail Track Corporation, Transport Safety Victoria, Public Transport Victoria, Transport Accident Commission, Roads Corporation (VicRoads) and V/Line Passenger Pty Ltd. Professor Paul Salmon's contribution to this article was funded through his Australian Research Council Future Fellowship (FT140100681).

## References

- [1] Independent Transport Safety Regulator. (2011). *Level Crossing Accidents in Australia*. ITSIR, Sydney
- [2] Australian Transport Safety Bureau. (2012). *Australian Rail Safety Occurrence Data: 1 July 2002 to 30 June 2012* (ATSB Transport Safety Report RR-2012-010). Canberra, Australia: ATSB
- [3] Read, G., Salmon, P. M., Lenne, M. G. (2013). Sounding the warning bells: the need for a systems approach to rail level crossing safety. *Applied Ergonomics*, 44, 764-774.
- [4] Salmon, P. M., Read, G., Stanton, N. A., Lenné, M. G. (2013). The Crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. *Accident Analysis and Prevention*, 50, 1278-1288.
- [5] Wilson, J. R., Norris, B. J. (2005). Rail human factors: Past, present and future. *Applied Ergonomics*, 36:6, 649-660
- [6] Salmon, P. M., Lenne, M. G. (2015). Miles away or just around the corner: systems thinking in road safety research and practice. *Accident Analysis and Prevention*, 74, 243-249.
- [7] Vicente, K. J. (1999). *Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work*. Mahwah, NJ: Lawrence Erlbaum Associates.
- [8] Cornelissen, M., Salmon, P. M., McClure, R. & Stanton, N. A. (2013): Using cognitive work analysis and the strategies analysis diagram to understand variability in road user behaviour at intersections, *Ergonomics*, 56:5, 764-780

- [9] Jenkins, D. P., Stanton, N. A., Salmon, P. M. & Walker, G. (2011). A formative approach to developing synthetic environment fidelity requirements for decision-making training. *Applied Ergonomics*, 42, 5, 757-769
- [10] Rechard, J., Bignon, A., Berruet, P., Morineau, T. (2015). Verification and validation of a Work Domain Analysis with turing machine task analysis. *Applied Ergonomics*, 47, 265-273
- [11] Stanton, N. A., Bessell, K. (2014). How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis, *Applied Ergonomics*, 45:1, 110-125
- [12] McIlroy, R. C., Stanton, N. A. (2011). Getting past first base: Going all the way with Cognitive Work Analysis, *Applied Ergonomics*, 4:22, 358-370
- [13] Jenkins, D. P., Stanton, N. A., Salmon, P. M., & Walker, G. H. (2009). *Cognitive work analysis: coping with complexity*. Ashgate, Aldershot, UK.
- [14] Salmon, P. M., Lenne, M. G., Read, G., Mulvihill, C., Young, K., Cornelissen, M., Walker, G. H., Stanton, N. A., Stevens, N. (Under review). More than meets the eye: using cognitive work analysis to identify design requirements for safer rail level crossing systems. *Applied Ergonomics*.
- [15] Salmon, P. M., Beanland, V. Lenne, M. G., Filtness, A., Stanton, N. A. (2013). Waiting for warning? Driver situation awareness at rail level crossings. In M. Anderson (Ed.), *Contemporary Ergonomics and Human Factors, Proceedings of the international conference on Ergonomics & Human Factors 2013, Cambridge, UK, 15-18 April 2013*
- [16] Young, K. L., Lenne, M. G., Beanland, V., Salmon, P. M., Stanton, N. A. (2015). Where do novice and experienced drivers direct their attention on approach to urban rail level crossings? *Accident Analysis and Prevention, Volume 77*, 1-11
- [17] Beanland, V., Lenne, M. G., Salmon, P. M., 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 Australasian Road Safety Research, Policing and Education Conference 2013, Brisbane, Australia*
- [18] Eason, K. (2014). Afterword: The past, present and future of sociotechnical systems theory. *Applied Ergonomics*, 45:2, 213-220