Actualising a Safe Transport System through a Human Factors Systems Approach

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Abstract. 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 that are more consistent with systems thinking and that significantly improve safety.

Keywords: Transport safety, systems approach, human factors, rail level crossings.

1 Introduction

In efforts to increase road safety many jurisdictions have followed the early leads by the Swedish and Dutch governments in introducing safe system approaches to road safety. This is certainly the case in Australia where both state and national strategies advocate for a safe system. Yet the approaches within these strategies typically take a reductionist approach where safety issues are considered in isolation. The key to successful implementation of such an approach lies in the consideration of human performance in the context of the wider system in which it takes place, and the acquisition of appropriate evidence to support systems-based strategy development. While these approaches have led to safety improvements there is now a growing body of

D. Harris (Ed.): EPCE/HCII 2013, Part II, LNAI 8020, pp. 29–35, 2013.
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literature that illustrates that more systematic approaches to safety management can produce more significant and long-term benefits. Systems theory has underpinned advances in complex sociotechnical systems [1] and led to the latest drift into failure model of system safety [2]. While road safety is such a system, the important features of systems theory are not found in the current road safety approach. There have been calls for these human factors-driven approaches to be applied to road safety [3].

Given this, what does it mean to implement road safety interventions that are truly safe system compliant? Does it mean introducing measures that are consistent with systems theory? Or does it mean implementing measures that achieve a prescribed safe system standard but yet continue to address road safety issues in isolation? Current road safety practice would suggest the latter. Road safety needs to go through a paradigm shift, inspired by systems approaches, to truly achieve a safe system. How can this paradigm shift be realised, and what is the conceptual framework that can take us there?

This paper considers these questions and the safe system concept in a complex part of the transport system, rail level crossings (RLX; highway-rail grade crossings in US terminology). This is a particularly interesting area of application as it features in both rail and road strategies in Australia. In recognizing the need for new approaches to safety in the RLX context, 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. Specifically, the program aims to:

1. Develop a systems-based model of RLX operation, informed by data collection and analysis of established theories, methods and models;
2. Use the model outputs to specify the optimum functionality and characteristics of interventions to prevent RLX crashes, and to prioritise existing interventions for testing and refinement; and
3. Evaluate driver responses to novel interventions, using advanced driving simulation, and propose effective and cost-efficient solutions to shape policy and standards to reduce RLX crashes.

This paper discusses the overarching framework we have adopted to achieve these aims, while specific examples within each analytical phase will be provided in the conference presentation. In the paper we firstly illustrate how existing approaches in this area are having modest success. Secondly, we introduce the paradigm shift needed, namely the systems approach. Thirdly, we present an approach to actualising the systems approach.

2 The Current Approach to RLX Safety

In 2008 there were 58 collisions between trains and vehicles at level crossings in Australia, which led to 33 fatalities and serious injuries [4]. Such incidents typically involve road user errors and violations, traumatic injury, and have a significant economic impact on both networks. This is particularly so for heavy vehicle collisions as they have a much greater potential to derail the train.

Our recent review of RLX research highlighted that achieving acceptable levels of performance and safety at RLXs has proven difficult [5], partly because RLXs are not homogeneous. RLXs are typically classified as one of two types: RLXs with active warnings (e.g., flashing red lights), or passive crossings (protected by stop or give way signs). Further, there are differences in the volume of rail and road traffic, the type and speed of traffic, overall RLX geometry, and so on. All of these factors influence fundamental aspects of human performance (including perceptual processes and expectations) that shape road user behaviour and thus the appropriate solution. Across Australia there are approximately 9,400 rail level crossings, with 6,060 passive (60%), 2,650 (30%) active, and 690 (10%) having other forms of control. Current solutions to the problem, such as grade separation and installation of boom gates, provide significant safety improvements but are cost-prohibitive (Wigglesworth & Uber, 1991). The effectiveness of lower cost interventions, such as education campaigns, speed limit reductions, rumble strips, train strobe lightings and in-vehicle warnings remains largely unknown, with the evaluations conducted to date being poorly designed and lacking a sound theoretical underpinning [5].

Key to developing effective RLX crash interventions is an in-depth understanding of the RLX system, including the performance of, and interactions between, its component parts (road users, vehicles, trains, train drivers, infrastructure etc). Although a limited number of models have been developed, currently we do not possess this systemic understanding. The research to date has been driven by an individual road user viewpoint, and therefore does not fully consider the wider RLX system factors that shape road user performance.

Our understanding of RLX system operation and road user behaviour at RLXs is therefore currently limited [5]. The focus of existing research on individual factors is a critical shortfall given the recent theoretical advances within the discipline of Human Factors that emphasise the need to take a systems perspective when evaluating, modelling, and supporting the performance of complex sociotechnical systems. The need to take the entire system, comprising human operators, tools, artefacts, and technologies and the interactions between them as the unit of analysis rather than the individuals working within it has been advocated [7, 8]. While existing theories of human performance (e.g., information processing) and models of driver behaviour provide a solid foundation, a new approach is needed to drive intervention development that recognises broader systemic influences on RLX crashes. Our recent review of level crossing intervention research identified the lack of a systemic model that describes how road users interact with level crossing infrastructure as a major gap in the area [5]. The traditional approach to this issue, while important, has not taken us forward in terms of improving safety for some time as these interventions for road user behaviour and level crossing safety have not been assessed from a true systems perspective.

3 The Human Factors Approach

The approach we are adopting to reducing RLX trauma involves collection of data to better understand the nature and performance of different RLX systems, and then development of models of RLX system performance using contemporary methods. This involves the use of theoretically underpinned, systems-based methods, including Hierarchical Task Analysis (HTA) [9] and Cognitive Work Analysis (CWA) [10, 11]. Following this, the analyses are used to evaluate existing interventions, and to inform the design and specification of novel interventions designed to treat the problem of RLX crashes. The final phase will use advanced driving simulation and on-road methods to test and refine the interventions proposed. An overview of the process is provided in Figure 1.

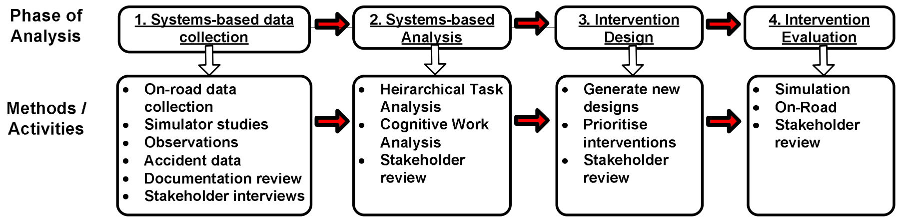

Fig. 1. An overview of the human factors-based systems approach to safety research and intervention design

3.1 Data Collection and Model Development

The application of HTA and CWA in a complementary manner has previously been used for system design and evaluation in other areas such as process control and the military. The outputs from each approach describe the system in a different but complementary manner, which is particularly powerful for system design and evaluation. For example, HTA describes the system normatively, in terms of what currently happens, whereas CWA describes the system formatively, in terms of what could potentially happen. The use of both methods together in an integrated manner, although used in the past in other complex safety critical domains, is novel with regard to road and rail safety.

The development of both models (HTA and CWA) is supported initially by data collected from a range of activities, including observational studies, documentation review, subject-matter interviews, and walkthrough analyses, all of which have previously been used to support previous model development using HTA and CWA [10, 12]. The use of driving simulation and on-road methods to study road user behavior also provides novel insights into the role of the RLX system in shaping behavior.

In this regard we have already conducted two studies using instrumented vehicles to study driver behavior at RLX in both regional and metropolitan settings. In addition to the standard suite of vehicle-based and eye-movement measures [13], measures of driver cognitive process and strategies were also derived via the use of verbal protocol analysis (i.e. think aloud) during the drive [14], and then post drive ‘critical decision method’ interviews, which are designed to explore the cognitive processes underpinning task performance and decision making. Data of this type have not previously been collected at RLXs and are required to underpin both the development of the RLX models and future research efforts.

3.2 The Systems-Based Methods of Analysis

The data collected are being used to construct HTA descriptions of different RLXs systems (e.g. passive versus active, metro versus rural). The outputs provide goal-based models of RLX system operation and will be used to inform our understanding of RLX system operation. They are also used for evaluating existing interventions and for generating and refining novel intervention designs. Additional human factors analyses modules applied to the HTA descriptions, including interface design and evaluation and error identification will be particularly useful for the intervention development and evaluation phases of the research.

The second analytical component is provided by the Cognitive Work Analysis framework which is currently receiving great attention as a comprehensive complex system evaluation and design approach. CWA is an ecological interface design-based framework that is concerned with constraints (rather than goals), which is based on the notion that making system constraints explicit in interfaces and displays potentially enhances human performance. The underlying premise of CWA is that one cannot understand cognition without first understanding the nature of the work domain. Further, CWA is formative and so, rather than normatively prescribe how work should be done or describe how it is currently being done, it seeks to identify how work could be done if the appropriate tools were made available, which is particularly important for system design efforts.

We have completed the CWA for active and passive RLX. Examples of how we worked through these analyses, and their outputs, will be provided in the conference presentation.

3.3 Design of Interventions

The CWA approach is used to generate new system designs, in terms of tools, interfaces, task allocation, and social organisation. This step will involve the use of the CWA outputs in conjunction with Human Factors, road and rail SMEs, to generate new RLX crash intervention design specifications. Specifically, a workshop will be held with researchers, SMEs and project partners, whereby the CWA outputs will be used to drive novel intervention design specification. Whereas CWA has in the past been used as a revolutionary design approach, the utility of HTA lies in its use as an evolutionary design approach. This step will involve the use of HTA and its range of extended analysis modules (e.g., error identification, interface design) to refine the interventions identified.

The output of these steps will be a series of candidate intervention designs for further testing. Importantly, at this stage the interventions chosen for scientific evaluation during phase 3 of the project will have been selected and refined based on exhaustive, systems-based models of RLX performance and expert opinion.

3.4 Evaluation of Interventions

Simulation is an excellent and established method to test any number of system-based interventions that might emerge during earlier phases of the research.

In preliminary research we have established that controlled and safe exposure to rare events (encounters with trains) can be achieved using simulation [15]. The class of performance measures that can be used include the following:

1. Vehicle-based measures including: mean and standard deviation of lateral position, mean speed and speed profiles on approach to RLXs and reaction time.
2. Compliance with RLXs as measured by proportion of drivers who come to a stop when a train approaches.
3. Driver eye movements, including object detection times and fixation durations to be measured. This provides for more theoretical hypothesis testing related to attentional strategies adopted by road users.
4. Subjective data collected via post-drive interviews regarding driver perceptions of the interventions trialled and understanding of required behaviours at RLXs.

Following simulator evaluation, selected interventions can be implemented in the field, after which point the on-road methods of assessment are appropriate.

4 Conclusion

Approaches to safety research and management that take a systems approach are more likely to generate effective interventions. Several authors have called for such approaches to be applied to transport settings. In recognizing the need for new approaches to safety in the RLX context, 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. The approach we are using initially involves the collection of new data on the ways in which the RLX system shapes road user behaviour. The second component involves a conceptualisation and analysis of the RLX system using methods that are congruent with systems thinking. The use of these outputs to support new intervention design and evaluation are the final components.

To this point we have completed the first phase identified in Figure 1, the data collection. In doing so we have provided new data on the factors that shape road user behavior at RLX. The phase 2 analyses using CWA are almost complete and provide a very different and novel means for conceptualizing and representing the RLX system. It is our hope and intention that the analytical process we are adopting will serve a model that can guide others in actualizing a safe road and rail transport systems.

Acknowledgements. This project is funded by an Australian Research Council Linkage Grant (LP100200387) to Monash University in partnership with the Victorian Rail Track Corporation, Transport Safety Victoria, Public Transport Victoria, Transport Accident Commission, Roads Corporation (VicRoads) and V/Line Passenger Pty Ltd. We gratefully acknowledge the support of the project partners and community participants. Paul Salmon's contribution to this research and article is funded through the Australian National Health and Medical Research Council post-doctoral training fellowship scheme.

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