Applied Ergonomics 53 (2016) 312–322

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

More than meets the eye: Using cognitive work analysis to identify design requirements for future rail level crossing systems

Paul M. Salmon [a,*], Michael G. Lenné [b], Gemma J.M. Read [b], Christine M. Mulvihill [b], Miranda Cornelissen [c], Guy H. Walker [d], Kristie L. Young [b], Nicholas Stevens [a], Neville A. Stanton [e]

[a] University of the Sunshine Coast Accident Research (USCAR), Faculty of Arts and Business, University of the Sunshine Coast, Maroochydore, QLD 4558, Australia
[b] Monash University Accident Research Centre, Building 70, Clayton Campus, Monash University, Victoria 3800, Australia
[c] Aviation, Griffith University, Nathan Campus, Brisbane, QLD, Australia
[d] Institute for Infrastructure and Environment, Heriot-Watt University, Edinburgh EH14 4AS, UK
[e] Transportation Research Group, University of Southampton, Highfield, Southampton SO51 7JH, UK

ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form 2 June 2015
Accepted 15 June 2015
Available online 2 July 2015

Keywords:
Rail level crossings
Cognitive work analysis
Systems analysis
Road safety
Rail safety

ABSTRACT

An increasing intensity of operations means that the longstanding safety issue of rail level crossings is likely to become worse in the transport systems of the future. It has been suggested that the failure to prevent collisions 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 active rail level crossing systems in Victoria, Australia that was undertaken to identify design requirements to improve safety in future rail level crossing environments. Cognitive work analysis was used to analyse rail level crossing systems using data derived from a range of activities. 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.

1. Introduction

In the future, surface transport systems will be more complex, technology driven, and will experience a higher intensity of operations. The continuing failure to control safety in today's systems raises critical questions, many of which centre around how transport system design processes can be modified to produce safer environments. A key requirement is the use of appropriate design and evaluation methodologies that fully consider the complex sociotechnical nature of transport systems. Without such approaches, longstanding transport safety issues will get worse, not better. This paper argues that approaches from the realm of systems thinking provide appropriate methods for developing the safe and efficient transport systems of the future.

One intractable surface transportation issue is that of collisions at Rail Level Crossings (RLXs). RLX are 'at grade' intersections comprising rail vehicles and their infrastructure, and other travel modes, usually roads. In most cases the train has priority and other types of traffic have to be deconflicted with the train's movement. This is achieved by inducing other non-rail traffic to stop and wait until the train has passed. In engineering terms achieving this deconfliction is a simple problem. In many situations, particularly those appearing as high risk (such as busy roads or urban areas) numerous engineering countermeasures including signs, road markings, warning lights and barriers are in place. Despite this, system defences are often defeated leading to accidents that continue to occur at an unacceptable rate. Indeed, as other sources of risk on the railway have been successfully tackled the problem of RLXs has become increasingly exposed. In many jurisdictions it is now one of the foremost risks affecting the rail network (e.g. Office and Rail and Road, 2015; RISSB, 2009; Transport Safety Committee, 2014).

The accidents statistics make for sobering reading (e.g. Evans, 2011; Hao and Daniel, 2014). In Australia, for example, between 2000 and 2009 there were almost 700 collisions between road vehicles and trains at RLXs, leading to nearly 100 fatalities (Independent Transport Safety Regulator, 2011). Despite a range of safety initiatives being introduced, including educational campaigns, increased enforcement, and the upgrade of selected crossings to full active protection (e.g. flashing lights and boom gates), in 2011 there were 49 collisions between trains and road vehicles at Australian RLXs,

* Corresponding author.
E-mail address: psalmon@usc.edu.au (P.M. Salmon).

http://dx.doi.org/10.1016/j.apergo.2015.06.021
0003-6870/

leading to 33 fatalities (ATSB, 2012). The problem is not limited to collisions between trains and vehicles; between 2002 and 2012 there were 92 collisions between trains and pedestrians at RLXs (ATSB, 2012). In 2010, the annual cost of RLX incidents was estimated at just over one hundred million dollars, taking into account human and property damage costs and other costs such as emergency service attendance, delays, investigation and insurance (Tooth and Balmford, 2010).

Researchers have recently pointed to a lack of understanding of behaviour at RLXs and, more specifically, the interactions between people and the RLX infrastructure which give rise to unsafe behaviours (Edquist et al., 2009). Interactions like these are best understood using a systems approach (Salmon and Lenné, 2015). Such an approach is not common in level crossing design and safety (e.g. Read et al., 2013; Salmon et al., 2013; Wilson and Norris, 2005) but given the consequences and costs accruing from accidents and fatalities, there is clearly a need to pursue a different, and potentially more effective, line of enquiry. The alternative is to continue focussing on RLX components in isolation. This type of engineering based approach not only examines component parts (such as road users, warnings, or individual pieces of equipment) in isolation, but artificially splits the entire rail and road infrastructure, with each considered under a different jurisdiction in many cases. The outcome of this has been progress in solving the problems to which an engineering solution is effective, but severe difficulty dealing effectively with the prominent behavioural component of the problem.

The current approach, therefore, has tended to lead to incremental design changes that have only marginal effects. This 'fix the broken component' mentality, has received broader criticism. A deterministic focus, in which the problem is broken down and analysed at a component level, drives the outcomes towards fairly narrow solutions and is a limited approach to safety management (Dekker, 2011). It is also acknowledged to be an inappropriate approach to improving safety within complex sociotechnical systems, of which RLX are an example (Salmon and Lenné, 2015). This is because the interactions that occur within sociotechnical systems are not fully captured.

Developing appropriate reforms for RLXs that are in line with systems thinking requires first that an in-depth understanding of the RLX system be developed. Although this is seemingly an obvious requirement, such an understanding does not currently exist (Read et al., 2013). Indeed, despite repeated calls, a systems thinking approach to RLX safety is yet to materialise (Read et al., 2013). This article is a direct response to this knowledge gap and provides the first systems analysis of RLX systems in Victoria, Australia. Specifically, the outputs of a four phase Cognitive Work Analysis (CWA; Vicente, 1999) of actively controlled RLXs are presented. The aim is to synthesise and communicate the findings from each analysis phase and to generate a series of design requirements for future RLX systems.

2. Cognitive work analysis

CWA (Vicente, 1999) is a systems analysis and design framework that has previously been used both to analyse complex sociotechnical systems and to inform system design or redesign activities (e.g. Cornelissen et al., 2015; Jenkins et al., 2011; Rechard et al., 2015; Stanton and Bessell, 2014). An important feature of the framework is a focus on identifying the constraints imposed on behaviour within the system (Stanton et al., 2013). As a result, the design recommendations generated often centre on making constraints more explicit to users, removing constraints on behaviour or better exploiting existing constraints to support behaviour (Stanton et al., 2013).

The framework comprises five analysis phases (Vicente, 1999). In the present study the first four of these phases were used. The fifth phase, worker competencies analysis, was not applied in this case because it was felt that the analysis outputs from the first four phases provided a sufficiently in-depth account of RLX behaviour to support identification of areas for redesign. A brief description of each of the phases employed is given below along with a table showing example related RLX outputs (see Table 1).

2.1. Work domain analysis

The first phase, WDA, is used to provide an event and actor independent description of the system under analysis: in this case the RLX 'system'. 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 (Vicente, 1999). This is achieved by describing systems at the following five conceptual levels using the abstraction hierarchy method:

1. Functional purpose – The overall purposes of the system and the external constraints imposed on its operation;
2. Values and priority measures – The criteria that organisations use for measuring progress towards the functional purposes;
3. Generalized functions – The general functions of the system that are necessary for achieving the functional purposes;
4. Physical functions – The functional capabilities and limitations of the physical objects within the system that enable the generalised functions; and
5. Physical objects – The physical objects within the system that are used to undertake the generalised functions.

The output is a detailed description of the system under analysis in terms of the constraints influencing behaviour and the physical objects (and their affordances) and functions that enable the system to achieve its functional purpose. Importantly, the abstraction hierarchy model uses means-ends relationships to link nodes across the five levels of abstraction.

2.2. Control task analysis

The second phase, Control Task Analysis (ConTA), is used to examine the specific tasks that are undertaken to achieve the purposes, priorities and functions of a particular work domain (Naikar et al., 2006). Rasmussen's decision ladder (Rasmussen, 1976; cited in Vicente, 1999) and Naikar et al.'s (2006) Contextual Activity Template (CAT) are used for the ConTA phase. The decision ladder is used to describe the decision making processes that can be adopted during different tasks along with the short cuts through this process that can be made by users with differing levels of expertise. The CAT is used to map functions and affordances across different contexts and locations in terms of where they are currently undertaken and where they could potentially be undertaken given the existing system constraints.

2.3. Strategies analysis

The strategies analysis phase is used to identify all of the different ways or strategies through which the control tasks can be undertaken. The Strategies Analysis Diagram (SAD; Cornelissen et al., 2013) is one approach that can be used to conduct the strategies analysis phase. This builds on the WDA outputs by adding verbs and criteria to examine the range of strategies available within a given system based on the means-ends links between physical objects, affordances, and functions.