Applied Ergonomics 56 (2016) 1–10

Contents lists available at ScienceDirect

Applied Ergonomics

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

Using the decision ladder to understand road user decision making at actively controlled rail level crossings

Christine M. Mulvihill [a,*], Paul M. Salmon [b], Vanessa Beanland [c], Michael G. Lenné [a], Gemma J.M. Read [b], Guy H. Walker [d], Neville A. Stanton [e]

[a] Monash University Accident Research Centre, 21 Alliance Lane, Monash University, VIC, 3800, Australia
[b] Centre for Human Factors and Sociotechnical Systems, University of the Sunshine Coast, Maroochydore, QLD, 4558, Australia
[c] Research School of Psychology, College of Medicine, Biology and Environment, The Australian National University, Canberra, ACT, 2601, 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

A R T I C L E I N F O

Article history:
Received 3 November 2015
Received in revised form
22 February 2016
Accepted 26 February 2016

Keywords:
Rail level crossings
Road users
Decision making
Decision ladder
Safety

A B S T R A C T

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.

1. Introduction

Australia is no different to the rest of the world in experiencing significant safety issues at rail level crossings (RLXs). Approximately 100 incidents occur at Australian RLXs every year, resulting in the deaths of 37 people annually (Australian Transport Council, 2010). The Australian state of Victoria, the jurisdiction in which the authors conducted this research, accounted for almost one-third of the nation's 601 motor vehicle-train collisions at RLXs from 2002 to 2012, and 55% of its 92 pedestrian-train collisions over the same period (ATSB, 2012). Crashes at RLXs represent one of the key risks on the railway - significantly more common than other incident types such as Signals Passed At Danger (Transport Safety Victoria, 2014) - and incur an estimated annual cost of approximately AU$24.8 million (Cairney, 2003). Clearly, further research and development is required (Read et al., 2013).

The factors contributing to RLX collisions are complex and rarely involve single causes for any given incident (e.g. Lenné et al., 2011; Salmon et al., 2013; Tey et al., 2011). Human factors have been identified as the primary contributors, with observed driver compliance at boom barrier protected crossings ranging from as low as 62% (Meeker and Barr, 1989) to 86% (Witte and Donohue,

* Corresponding author.
E-mail addresses: christine.mulvihill@monash.edu (C.M. Mulvihill), psalmon@usc.edu.au (P.M. Salmon), vanessa.beanland@anu.edu.au (V. Beanland), michael.lenne@monash.edu (M.G. Lenné), gread@usc.edu.au (G.J.M. Read), G.H.Walker@hw.ac.uk (G.H. Walker), N.Stanton@soton.ac.uk (N.A. Stanton).

http://dx.doi.org/10.1016/j.apergo.2016.02.013
0003-6870/

2000). Unsafe decision making is typically manifested in failing to observe the train and/or to heed the warning signals (Wigglesworth, 1976), either deliberately or inadvertently, and has been explained in terms of perceptual factors, such as misperceptions of train speed and distance, and non-perceptual factors including expectations, motivations, and social norms (Cooper and Ragland, 2008; Yeh and Multer, 2008). Despite these explanations, the factors that influence road users' decisions to either stop at or proceed through the crossing are still not well understood (Edquist et al., 2009; Salmon et al., 2016), which limits the potential to achieve safe performance across RLX systems. Two particular issues that may be limiting progress in this domain are the theoretical and methodological frameworks within which behaviour at RLXs has thus far been examined.

2. Theoretical and methodological frameworks

2.1. Existing research

A key issue is that decision making has not been examined directly. Indeed, naturalistic decision making at RLXs has been examined in only a handful of studies (Beanland et al., 2015; Carlson and Fitzpatrick, 1999; Meeker and Barr, 1989; Pickett and Grayson, 1996; Read et al., 2014; Ward and Wilde, 1995); most of which have relied on roadside observational methods that have overlooked decision making from the road user's perspective. Where interviews have been used (e.g., Pickett and Grayson, 1996), little information is given about the basis for decision making beyond the reasons for non-compliant behaviour. No previous studies have examined naturalistic decision making processes in compliant road users, which is an important omission since understanding compliant behaviour at RLXs provides a basis to determine why non-compliance occurs and whether non-compliant behaviours are atypical. In addition, most studies have used only quantitative measures (e.g. driver speed, head movements, stop or go behaviour) to draw inferences about the perceptual and motivational factors underlying decision making, resulting in ambiguous conclusions. Lenné et al. (2011), for example, concluded that higher speeds on approach to crossings by non-compliant compared to compliant drivers may indicate: an inability to stop safely; a failure to see the crossing; a failure to understand the meaning of warnings signals; or an intentional violation. Without the decision maker's perspective, it was not possible to determine which of these scenarios were influencing behaviour. Similarly, Tenkink and Van der Horst (1990) interpreted fast acceleration on approach to the crossing to infer that the drivers were committing an intentional violation. However, it is equally plausible that the drivers had failed to notice the warnings and proceeded to cross unintentionally, or were responding to features of the environment in a way that was not captured by the study paradigm.

2.2. Systems thinking

Existing explanations of behaviour at RLXs have focussed largely on human performance in isolation from system wide factors which enable or constrain it (e.g., Lenné et al., 2011; Meeker et al., 1997; Tenkink and Van der Horst, 1990; Ward and Wilde, 1995). A RLX does not just describe the unified collection of railway engineering (the lights, boom gates and so forth), it also describes the environment in which it is placed, and both types of user (rail and road). It is not common to view the RLX as a system, although there are some exceptions (e.g., Read et al., 2013; Salmon et al., 2013; Yeh and Multer, 2007). Existing approaches are based on the assumption that if errant 'component' behaviours are removed from the system, such as via increased enforcement of laws, better education or more engineering countermeasures, then the system will be safer (e.g., Read et al., 2013; Reason, 1997). This 'broken component' view does not fully take account of how these various system parts interact to give rise to emergent properties (Salmon et al., 2015), such as accidents and near misses, which are difficult to predict or else confound common-sense engineering and enforcement countermeasures.

While it is fair to say that progress has been made in improving RLX safety, it is still the case that behaviours emerge which severely degrade safety performance. For example, the crash at Kerang in Victoria in which a loaded semi-trailer struck a passenger train, resulting in 11 fatalities on the train, occurred even where flashing lights were operating at the RLX (Salmon et al., 2013). Crashes like these have provided an impetus for the rail industry to question traditional approaches, and this appetite for new approaches aligns with systems approaches to understanding and enhancing performance in safety critical domains (e.g., Dekker, 2011; Edquist et al., 2009; Leveson, 2004; Rasmussen, 1997; Read et al., 2013; Reason, 2000; Salmon et al., 2012; Wilson and Norris, 2005).

A key feature of the systems approach is that all relevant components within the system are considered (e.g., Read et al., 2013). This is important as different road users interact with each other and with the RLX system in different ways, and factors that impact positively on one group may impact negatively on another group and vice-versa. Although different road users are exposed to RLXs, Read et al. (2013) found that only 30% of publications within this area examined more than one road user group, with most single road user analyses focussing on motorists only. In addition, accident statistics and observational studies tend to group different road users under the one category; such as cyclists with pedestrians and motorcyclists with car and truck drivers (ATSB, 2012). We know from this same accident data that other classes of crossing user are very well represented, with vulnerable road users comprising half of all RLX casualties (see Beanland et al., 2015 for a review). For this reason it is crucial to understand decision making of all road users at RLXs, in order to ensure that interventions and countermeasures are appropriately designed to support the range of system users.

2.3. Rasmussen's decision ladder

Read et al. (2013) have argued strongly for a systems approach to analysing safety at RLXs. Cognitive Work Analysis (CWA) (Vicente, 1999; Jenkins et al., 2008) is a systems analysis framework that focuses on the constraints shaping performance within complex sociotechnical systems. CWA has previously been applied across a range of safety critical domains for the purpose of systems analysis and design (Jenkins et al., 2008) and has recently been applied to understand RLX systems (Salmon et al., 2016). In this paper, we focus on the second phase of CWA, Control Task Analysis (ConTA). ConTA is used to investigate in-depth key tasks undertaken within the system of interest (Vicente, 1999) including activity analysis in "decision-making terms" (Rasmussen et al., 1994, p.58). ConTA uses the decision ladder (see Fig. 1); a template designed by Rasmussen (1974, cited in Vicente, 1999) representing the generic categories of activity that are necessary to support decision making and task completion (Rasmussen, 1974, 1976, cited in Vicente, 1999).

The decision ladder comprises boxes representing information processing activities, and circles representing states of knowledge that are the results of those activities (Naikar, 2010). The left side of the decision ladder is concerned with the observation and assessment of the current system state, whereas the right side of the decision ladder is concerned with the planning and execution of tasks and procedures to achieve a target system state. Option