Challenging conventional rural rail level crossing design: Evaluating three new systems thinking-based designs in a driving simulator

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**A B S T R A C T**

The road-rail interface is hazardous for both road vehicles and trains, with collisions often resulting in serious injury and deaths of drivers and passengers. This is a major problem worldwide, and there is currently no appropriately effective low-cost solution for rural areas. Grade separation is prohibitively costly for most rail level crossings. This research evaluated three proposed new, relatively low-cost design solutions: GPS Average Speed interface, Simple but Strong crossing and Ecological Interface Design crossing. These new designs were compared with the conventional passive and active rural rail level crossings in a driving simulator. The findings suggest that there is a preference for the standard rail level crossings, probably because this is what drivers are used to. Of the new designs, the Ecological Interface Design rail level crossing seemed to perform the best in the simulator study, and could be implemented at a lower cost than conventional active rail level crossings. However, all three designs had apparent strengths and weaknesses. These findings highlight possible design solutions that should be further tested in real-world field trials.

1. Introduction

Collisions at rail level crossings (RLXs; a.k.a. *highway-rail grade crossings*) are a significant public safety concern worldwide (Chadwick et al., 2014; Hu et al., 2010). Fatalities in RLX collisions comprise nearly half of all rail fatalities in Australia, excluding cases of suicide or suspected suicide (ONRSR, 2016).

RLXs reside throughout the road network and pose unique challenges depending on the local context (Salmon et al., 2014). In urban areas, RLXs are often situated in complex visually-cluttered environments, with relatively high rail and road traffic (Palat et al., 2017; Young et al., 2015), and typically have active warnings such as boom barriers and flashing lights. In contrast, rural RLXs usually have low train volumes and only passive warnings, such as road markings and static signs (Rudin-Brown et al., 2014; Salmon et al., 2013). The most effective existing solutions for improving RLX safety, namely grade separation and installing boom barriers, are prohibitively expensive (Cairney et al., 2002; Wigglesworth and Uber, 1991), especially for low-traffic rural areas. Many lower-cost countermeasures have either been found to be ineffective, or have not been appropriately evaluated (Edquist et al., 2009; Saccomanno et al., 2007). Lower-cost evidence-based RLX designs are needed to improve safety in rural areas (Wullems, 2011). We argue that such designs can be achieved by adopting a different approach to data collection, interpretation and countermeasure design.

The first step in generating new evidence-based designs is to accumulate information on current RLX system functioning and the task requirements imposed on road users. For the current study, this was achieved through several studies examining behaviour at RLXs, including on-road (Beanland et al., 2017; Lenné et al., 2013; Salmon et al., 2013; Young et al., 2015), observational (Read et al., 2017) and self-report studies (Beanland et al., 2016). This yielded in-depth data, which formed the basis of Cognitive Work Analysis (CWA; Vicente, 1999) outputs describing the RLX system (Mulvihill et al., 2016; Salmon et al., 2016; Read et al., 2017). The CWA outputs generated crucial new insights to guide the design of novel RLX interventions. These revealed fundamental differences in how road users experience passive versus active and rural versus urban RLXs, as well as factors that influence decision-making and behaviour in each context. The CWA process also revealed potential conflicts between different functional purposes of the existing RLX system (e.g., “minimise delays” conflicts with “protect users” if safety is managed by requiring road users to...
yield for trains).

Key issues identified included that rural RLXs: (i) are situated on high-speed roads; (ii) often lack active protection, especially barriers/gates; (iii) may not be noticed by drivers (i.e., if they are not expecting an RLX); and (iv) may have the speed and/or distance of an approaching train misjudged by road vehicle drivers (Read et al., 2016, 2017). These findings prompted a strong recommendation for new low-cost rural RLX designs to minimise these risks (Read et al., 2017).

The CWA Design Toolkit (Read et al., 2015) approach was applied to generate novel RLX concepts designed to create safer behaviours. This process involved two workshops with road and rail stakeholders and experts (Read et al., 2016), which generated two rural RLX design concepts: the GPS Average Speed interface and Simple but Strong crossing. A final workshop was held with human factors researchers to create an additional design called the Ecological Interface Design (EID) crossing, reflecting the design philosophy that inspired it. All three concepts were subjected to desktop evaluation, and design refinements and alterations were adopted to maximise their potential performance (Read et al., 2016).

Two of the designs were underpinned by the EID philosophy (Vicente and Rasmussen, 1992), which asserts that design specifications should consider both constraints within the system that limit behaviour, and inherent limitations of the human users, and make key constraints explicitly visible to users. This accords with Rasmussen’s skills, rules, knowledge taxonomy (Vicente and Rasmussen, 1988), which outlines three levels of cognitive control that may be employed in information processing. Skill-based behaviour involves automatic responses to environmental cues, whereas rule-based behaviour involves activating stored knowledge or procedures based on environmental cues, and knowledge-based behaviour requires analytical processing of the situation and appropriate responses (McIlroy and Stanton, 2015). Each level differs in the amount and nature of information required; the ideal EID interface should support both analytical problem-solving and direct perception-based action. Crucially, the interface should not force users to adopt a higher level of cognitive control than is necessary (e.g., in simple, familiar situations, users should be allowed to rely on skill-based behaviour). Evaluations have found EID interfaces achieve superior performance when compared with conventionally designed interfaces, across a range of domains from healthcare to nuclear power (Burns and Hajdukiewicz, 2004; Sanderson, 2006; Vicente, 2002; Young and Birrell, 2012).

1.1. Evaluation process

The current study used a driving simulator to evaluate how drivers performed with each design. Simulators are commonly used to compare RLX infrastructure treatments under controlled conditions (Cale et al., 2013; Lenné et al., 2011; Liu et al., 2016; Rudin-Brown et al., 2012; Tey et al., 2011), including non-standard and novel treatments (Conti et al., 1998; Larue et al., 2016; Tey et al., 2013). Although simulators make it possible to incrementally introduce new designs one component at a time, the current study deliberately evaluated each novel design as an entire system with all new components introduced simultaneously, to capture overall system functioning including interactions between components. This approach was adopted because the designs were explicitly created to exemplify systems thinking principles (Read et al., 2017).

Three new designs were compared with two existing designs: a standard passive RLX with a Give Way (yield) sign, and a standard active RLX with flashing lights and bells but no boom barriers. These standard designs are common throughout rural Australia, and represent the RLXs that would be most likely to be replaced with a novel low-cost RLX design. Participants encountered all five RLX designs several times each under normal conditions, both with and without a train present, with all infrastructure and equipment functioning normally. Performance was assessed via objective and subjective measures including travel speed, situation awareness (measured using think-aloud verbal protocols), workload, usability, and relative rankings of each design. We have previously used a similar multi-measure approach in on-road studies examining driver behaviour at real-world RLXs (Beanland et al., 2017; Lenné et al., 2013; Young et al., 2015).

1.2. Design concepts

The three design concepts are summarised below; Section 2.3 describes how these were implemented in the driving simulator.

1.2.1. GPS Average Speed interface

The GPS Average Speed interface focuses on road user speed management and comprises an in-vehicle display designed to encourage drivers to make small speed adjustments over long distances (1–2 km), which would obviate the need to stop completely for an approaching train. The aim is to promote efficiency and traffic flow as well as safety, especially for large and heavy vehicles that have trouble slowing to a complete stop and then resuming cruising speed. The design does not necessitate changes to signs or signals at the RLX, but requires new vehicle-to-vehicle or vehicle-to-infrastructure communication.

The GPS interface was designed in accordance with EID principles (Vicente and Rasmussen, 1988, 1992), especially the notion that design should make system constraints explicitly visible to users. Here the most relevant constraints were the road user’s speed and the approaching train. To support skill-based behaviour, the GPS interface was integrated into the vehicle speedometer, with coloured bands used to represent “safe” (green) and “unsafe” (red) speeds (see Fig. 1). The green band indicates the driver is travelling at a legal speed that would avoid a conflict with a train at the RLX, whereas the red band indicates the driver is exceeding the speed limit and/or travelling at a speed that could potentially lead to a collision with a train (i.e., if the road user does not stop or substantially slow). This dynamic display enables drivers to determine the extent of speed reduction required (if in the unsafe zone) or the limits of how much they could increase their travel speed (if in the safe zone). The speed guidance system only activates

Fig. 1. GPS Average Speed interface showing safe (green) and unsafe (red) speeds on approach. Upper panel represents a user travelling within the safe speed zone; lower panel represents a user travelling within the unsafe speed zone. (Please refer to online version for colour figures.)
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