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An on-road network analysis-based approach to studying driver situation awareness at rail level crossings

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ABSTRACT

Crashes between cars and trains at rail level crossings are problematic worldwide. Despite this, key facets of driver behaviour at rail level crossings, such as situation awareness and decision making, remain ambiguous. This is largely down to the inability of existing methodologies to describe or evaluate the cognitive aspects of driver behaviour when negotiating rail level crossings. This paper showcases an on-road approach for examining driver situation awareness at rail level crossings. The study presented involved participants, classified either as novice or experienced drivers, providing concurrent verbal protocols as they drove a pre-determined urban route incorporating four rail level crossings. Driver situation awareness was modelled using a network analysis-based approach and the structure and content of the networks was assessed. The analysis revealed key differences between novice and experienced drivers situation awareness at rail level crossings. In closing, the benefits of the on-road approach are discussed and a series of wider driver behaviour applications are proposed.

1. Introduction

Crashes at rail level crossings represent a significant road and rail safety problem, both in Australia and worldwide. For example, during 2008, there were 58 collisions between trains and vehicles at rail level crossings in Australia, which led to 33 fatalities and serious injuries (ATSB, 2009). Further, across the European Union there were 2592 accidents and 892 fatalities at rail level crossings during 2007–2008 (European Railway Agency, 2009). In addition to fatalities and injuries, the cost and disruption to road and rail networks is significant. For example, the annual cost of rail level crossing crashes in Australia was recently estimated to be around $24 million (Wullems, 2011). Taken together, the high levels of trauma, disruption and financial cost associated with rail level crossing crashes renders them a key road and rail safety issue. Accordingly, they currently represent a priority area for rail organisations and research groups across the world (e.g. Evans, 2011; Lenné et al., 2011).

Despite widespread research focussing on rail level crossing safety, various aspects of rail level crossing performance remain poorly understood. In particular, key aspects of driver behaviour in this context, such as situation awareness (SA), decision making, and driver error, remain ambiguous. Although the causes of crashes at rail level crossings generally remain poorly understood (Lenné et al., 2011), one factor that has previously been implicated in rail level crossing crashes is poor SA on behalf of the vehicle drivers involved (e.g. Office of Chief Investigator, Transport and Marine Safety Investigations, 2007). Despite this, the normally ubiquitous concept has not yet been explored in the context of rail level crossings. This is largely because the methodologies used previously to assess SA have limitations which make assessment in the level crossing context difficult. Moreover, the methodologies previously applied to investigate driver behaviour at rail level crossings do not support the description or assessment of SA. The aim of the exploratory study described in this article was to test an on-road methodology for assessing driver SA in the rail level crossing context. Specifically, the authors wished to model driver SA when negotiating rail level crossings with a view to ascertaining what it comprises and how it differs across drivers of differing experience levels.

2. Situation awareness at rail level crossings

SA, the concept that describes how operators in complex systems develop and maintain awareness of 'what is going on' (Endsley, 1995a) is a critical commodity when driving, with poor SA, or components of it, having previously been identified as key causal factors in road traffic crashes (e.g. Klauer et al., 2006; Treat

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et al., 1979; cited in Gugerty, 1997). In a driving context, SA can be defined as activated knowledge, relating to the driving task, at a specific time, within the road transport system. From a road user perspective, this knowledge encompasses the relationships between road user goals and behaviours, vehicles, the road environment and infrastructure (Salmon et al., 2011).

The concept has much to offer when attempting to understand the mechanisms involved in rail level crossing crashes. For example, driver non-compliance with rail level crossing controls is one problem that leads to rail level crossing crashes (e.g. Lenné et al., 2011; Tey et al., 2011). One particularly prevalent form of non-compliance is unintentional non-compliance, whereby drivers fail to detect warnings or comprehend their meaning, and enter the level crossing as a train is approaching (Lenné et al., 2011). In Australia, for example, it has been estimated that instances of unintentional compliance account for almost half of all rail level crossing crashes (ATSB, 2002). From an SA perspective, issues surrounding diminished SA are likely to be at the root of unintentional noncompliance by drivers at rail level crossings. Although SA is contingent upon various factors, contemporary models suggest that it is underpinned by *genotype* and *phenotype* schema (Stanton et al., 2009); genotype schema represent schema held in the mind of individuals which contain prototypical responses to specific situations, whereas phenotype schema represent the state specific activated schema which is brought to bear in a particular situation. It is these schema which drive, and determine the content of, driver SA, since they direct exploration in the world (i.e. sampling of the environment), which in turn directs behaviour, which in turn modifies schema and so on (e.g. Neisser, 1976). Norman (1981) describes various schema-related failures that could potentially play a role in rail level crossing non-compliance, including activation of wrong schema, failure to active appropriate schema, and the faulty triggering of active schema. For example, when approaching an activated crossing (i.e. train approaching), activation of the wrong schema, caused by contextual conditions similar to those experienced at other 'inactive' crossings, could lead to diminished SA and delayed recognition of the crossing warnings. Moreover, drivers who hold inadequate schema for rail level crossings may not direct their attention to the appropriate rail level crossing warnings, increasing the likelihood that they will not comprehend the presence of a train.

Driving experience, in particular experience of rail level crossings, is therefore likely to be a key factor shaping driver SA and performance when negotiating level crossings. The schema perspective suggests that poorly developed schema may lead to inappropriate or inadequate interactions with the rail level crossing environment, which in turn can lead to a diminished level of SA. Previous investigations into drivers' attentional strategies (e.g. visual search) have demonstrated that novice drivers are vulnerable to driving errors associated with an inadequate visual search of the road environment (Underwood et al., 2002) and also that their visual search patterns may not differentiate between different road environments (Crundall and Underwood, 1998). This evidence is indicative of inadequate or incomplete schema which fails to incorporate all aspects of the road environment requiring attention. Further, in novices schema may be so oriented to vehicle control that they do not discriminate between different road environments. Whilst this adds weight to the *process* component of the schema SA argument, in that inadequate schema in novices results in an inadequate search of the environment, there is little in the driving literature which examines the *product* component of SA; that is what SA comprises in terms of activated knowledge at rail level crossings and how it differs across drivers of different experience levels. If inexperienced drivers have less well developed schema for rail level crossings than do experienced drivers, which in turn leads to differences in their attentional strategies, how does this manifest itself in differences in the content of SA across the two groups of drivers? The requirement for exploration in this context is further strengthened by the notion that the level of SA in terms of information derived from the environment does not necessarily equate with performance (e.g. Endsley, 1995b). Experts, for example, may derive less information from the environment, develop more parsimonious situational models, and yet perform efficiently (Walker et al., 2009). Thus the requirement to understand what SA comprises across drivers of differing experience levels is made even more important.

Investigating driver SA at rail level crossings, in particular, differences in SA across different road users of differing experience levels (and thus in possession of different schema), is thus an important step in understanding and preventing rail level crossing crashes. Previous research has demonstrated that SA differs across drivers of differing experience levels (e.g. Bolstad, 2001), and also that SA can be enhanced via driver training (Stanton et al., 2007; Walker et al., 2009) and in-vehicle technologies (Ma and Kaber, 2007). The potential to enhance driver SA at rail level crossings through system design, educational campaigns, and training is therefore compelling; however, before interventions are considered, a detailed understanding of driver SA at rail level crossings must first be developed. What driver SA comprises when negotiating rail level crossings and how it differs across different driver groups therefore represent key lines of inquiry for rail level crossing safety research.

3. Modelling and analysing situation awareness on the road

Examining driver SA at rail level crossings requires that their SA be modelled whilst they are engaged in non-contrived, naturalistic road scenarios involving the negotiation of rail level crossings. The majority of previous studies of SA in the driving context have been simulator-based (e.g. Ma and Kaber, 2005, 2007) using freeze probe techniques that cannot be applied in real world environments. Other approaches, such as post trial SA questionnaires, can be applied to real world driving; however, they provide only a subjective assessment of the quality of SA and not a description of what it comprises. Methodologies used previously to examine behaviour generally at rail level crossings are also limited in their capacity to describe or assess SA. Ostensibly to control for exposure to trains, previously rail level crossing research has primarily involved the use of driving simulation (e.g. Lenné et al., 2011), field observation (e.g. Tey et al., 2011) or retrospective accident analysis (e.g. Evans, 2011). Whilst these approaches are useful, and have no doubt enhanced the knowledge base on rail level crossing safety, various limitations abound when considering SA assessment. Most notable is that the cognitive processes of drivers engaged in real world scenarios cannot be examined. A useful addition to the area of rail level crossings research is therefore an approach whereby driver behaviour and cognition at rail level crossings can be examined on-road.

The proposed on-road methodology for assessing SA at rail level crossings involves the use of network analysis procedures to interrogate driver verbal protocol data. This approach has become popular as a way of modelling SA during real world tasks, including road transport (e.g. Salmon et al., 2011; Stanton et al., 2007; Walker et al., 2009, 2011). Recent descriptions of SA argue that it comprises concepts and the relationships between them (e.g. Stanton et al., 2006), which in turn make network analysis procedures highly suitable for SA assessments. Representing knowledge via networks is not new, with approaches such as semantic networks (Collins and Loftus, 1975) and concept maps (Crandall et al., 2006) having previously been used to represent knowledge via concepts and the associations between them.