USING THE DECISION LADDER TO UNDERSTAND ROAD USER DECISION MAKING AT ACTIVELY CONTROLLED RAIL LEVEL CROSSINGS

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Abstract

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. This paper represents an important step in responding to these issues. One-hundred and sixty-six RLX users, including drivers, motorcyclists, cyclists and pedestrians completed a diary entry for each of 457 naturalistic encounters with RLXs. 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. The findings show that, in some cases, engineering countermeasures intended to improve decision making (e.g. flashing lights), may have the opposite effect for some users because of system permits a high level of flexibility for circumvention. Non-motorised users were also more likely to access information outside of the warning signals because of their ability to achieve greater proximity to train tracks and the train itself. The major conundrum for design 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.

Keywords: Rail level crossings, road users, decision making, decision ladder, safety

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, Salmon, & Lenné, 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, Read, Stanton, & Lenné, 2013; Tey, Ferreira, & Wallace, 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 & Barr, 1989) to 86% (Witte & Donohue, 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 & Ragland, 2008; Yeh & 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, Stephan, Wigglesworth & Lenné, 2009; Salmon et al, In Press), 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, Lenné, Salmon & Stanton, 2013; Carlson & Fitzpatrick, 1999; Grayson & Picket, 1996; Meeker & Barr, 1989; Read, Salmon, Lenné & Grey, 2014; Salmon, Lenné, Young et al., 2010; Ward & 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., Grayson & Picket, 1996), little information is given about the basis for decision making beyond the reasons for non-compliant behaviour. No previous studies have examined 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, Fox, & Weber, 1997; Tenkink & Van der Horst, 1990; Ward & 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., 2010; Salmon et al., 2013; Yeh & 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 counter measures.

While it is fair to say that progress has been made 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. 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, McClure, & Stanton; 2012; Salmon & Lenné, 2014; 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 focusing 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, Lenné, Salmon, & Stanton, 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, In Press). 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, including "activity analysis in decision-making terms" (Rasmussen, Pejtersen, & Goodstein, 1994). ConTA uses the decision ladder (see Figure 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).

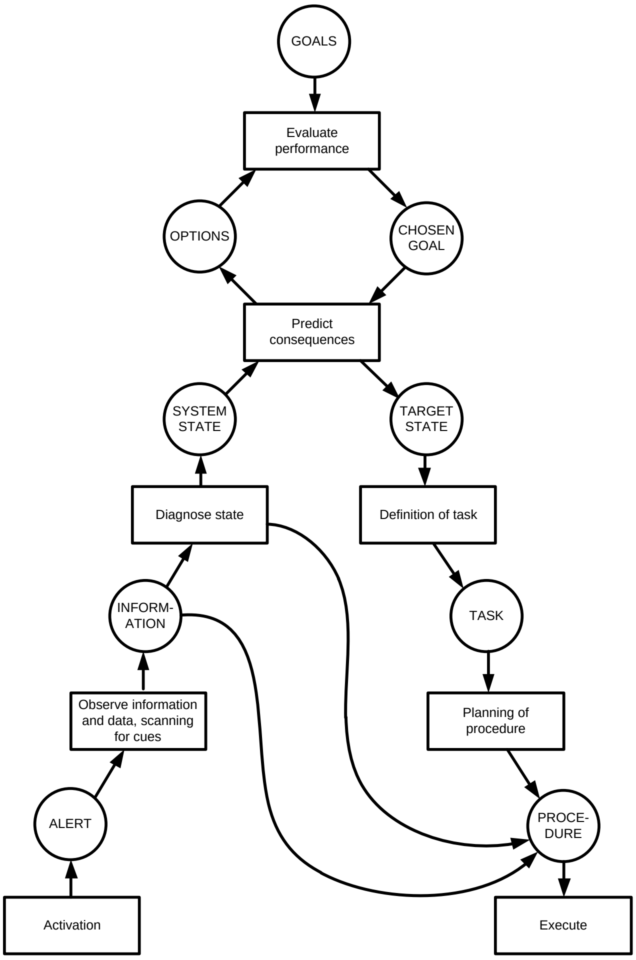

Figure 1. Decision ladder showing leap and shunt decision making pathways.

The decision ladder comprises boxes representing information processing activities, and circles representing states of knowledge that are the results of those activities (Naikar, 2008). 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 evaluation and goal selection link the two sides at the top of the ladder. The decision ladder represents a sequence of information processing steps (Vicente, 1999). Novices, or experts confronted with unfamiliar tasks, are expected to follow the decision ladder in a linear fashion, relying on rational, knowledge-based behaviour to make decisions. Expert users typically take short-cuts, relying on rule- or skill-based behaviour to carry out familiar tasks (Naikar, 2008). Two types of shortcut can be applied to the ladder. “Shunts” connect an information processing activity to a state of knowledge (box to circle) and “leaps” connect two states of knowledge (circle to circle). In the latter case, one state of knowledge is directly related to another without any further information processing (Jenkins, Stanton, Salmon, Walker, & Rafferty, 2010). The analysis presented in this article is based on the notion that, on approach to RLXs, users will proceed through the decision ladder, exhibiting skilled, rule or knowledge based processes, and leaps and shunts between them.

To elicit this and represent this information the Critical Decision Method (CDM; Klein, Calderwood, & MacGregor, 1989). This is a cognitive task analysis interview method that has been used extensively to investigate the cognitive processes underlying human performance and have been successfully used to investigate Naturalistic Decision Making in medical settings (Galanter & Patel, 2005); work place accidents (Salmon et al., 2011) emergency responses (Mendonça, 2007), aviation (Plant & Stanton, 2013) and driving (Walker, Stanton, Kazi, Salmon, & Jenkins, 2009). Application of the CDM to investigate decision making at RLXs provides an opportunity to overcome some of the limitations associated with earlier studies on this topic, and provide deeper insights into decision making behaviour across different forms of user. The aim of this article, therefore, is to investigate and compare the decision making of users who traverse RLXs in both a compliant and non-compliant manner. To do so, the findings derived from a CDM-based survey of user behaviour at RLXs is presented. The findings are mapped onto Rasmussen's decision ladder model in order to clarify the decision making processes adopted by the participants involved in the study.

3. Methodology

3.1. Design

A diverse sample of RLX users across four transport modalities (car drivers, motorcyclists, cyclists and pedestrians) completed a daily record of RLX exposure, with an additional CDM questionnaire (Klein et al., 1989) in order to reveal key features of decision making during encounters with trains or activated warning signals. Responses to CDM prompts were subject to content analysis to isolate features that could be mapped onto the decision ladder (Rasmussen, 1974, as cited in Vicente, 1999).

3.2. Participants

RLX users were 166 adults aged 18-71 years (*M* = 39.9, SD = 12.9, 57% male) residing in the Australian state of Victoria. The sample comprised 50 car drivers (30%), 39 motorcyclists (24%), 42 cyclists (25%) and 35 pedestrians (21%). Most participants resided in metropolitan Melbourne (80%), with the remaining 20% from regional Victoria. Participants were recruited through newsletters, local newspapers and mailing lists as well as websites for motorcycling or cycling interest groups. All participants were required to be regular users of RLXs (defined as crossing at least 3-4 times per week using the same mode of transportation). All participants were compensated for their time.

Ethics approval for the study was granted by the Monash University Human Research Ethics Committee.

3.3. Materials

3.3.1. Demographic questionnaire

Participants completed a short questionnaire at the commencement of the study to record details about their age, gender, place of residence, frequency of use of their nominated mode of transportation (number of times per week) and exposure to RLXs (number of hours per week).

3.3.2. Daily diary

Participants completed a daily 'diary' of all RLXs that they encountered during a two-week period. The diary included questions on the number and types of crossings encountered, whether a train was approaching, and the types of warnings in use at each crossing. In situations where a train was approaching and/or the active warnings were operational (i.e., lights flashing, boom barriers descending or down), participants were asked to record the details of the crossing based on a series of questions derived from CDM interview prompts (Klein et al., 1989). These included whether and why they stopped or proceeded through the crossing, the types of information they used to inform their decision, what their goal was, and what options they felt they had available (see Table 1).

Table 1. *CDM Probes used in the Daily diary*

Probe	Question	Answer type
Incident description	Please describe the situation when you approached the rail level crossing	Open-ended
	Describe how you knew whether a train was approaching	Open-ended
	Describe what you did at the rail level crossing and why you did it	Open-ended
Goal specification	What were your specific goals when you approached this level crossing?	Open-ended
Assessment	What were the conditions at the time of this rail level crossing encounter?	Closed ended; multiple options allowed
Cue identification	What first alerted you to the presence of the train or the activated warnings?	Closed ended; one option allowed
Situation awareness	What information did you use when you made your decision to stop or proceed at this level crossing?	Closed ended; multiple options allowed

Influencing factors	What factors influenced your decision to stop or proceed at this level crossing?	Closed ended; multiple options allowed
	What was the most important factor that influenced your decision to stop or proceed at this level crossing?	Closed ended; one option allowed
Decision making	What factors influenced your decision to stop or proceed at this level crossing?	Closed ended; one option allowed
Mental models	Did you think about the potential consequences of your decision to stop or proceed before you made it?	Closed ended; one option allowed
Experience	What previous experience or knowledge did you use when you made your decision?	Closed ended; multiple options allowed
Conceptual	Are there any situations in which your decision would have turned out differently?	Combined closed- and open-ended

3.4. Procedure

3.4.1. RLX users

Following completion of the demographic questionnaire, participants completed the daily diary at the end of each study day. Most diaries were completed using the on line website SurveyGizmo. A small number of participants completed the daily diary on paper and mailed all entries back to the researchers at the end of the two-week study period.

3.4.2. Descriptive analysis of crossing encounters

The analysis focused on actively controlled RLXs (i.e., those with bells, flashing lights and/or active barriers) when a train was approaching. Of the 166 participants who completed the study, 140 participants encountered 457 crossings that met these criteria. To ensure consistency in comparisons between road users, any encounters where a violation would likely have been impossible based on the distance of the road user from the crossing and/or their visibility of the crossing, were excluded from the analysis. For motorised road users, these encounters included heavy traffic conditions in which the user was not the first vehicle in the queue and/or, in the case of motorcyclists, did not filter to the front of the queue. Encounters by non-motorised road users were excluded if the road user's view of the RLX was blocked by an object or vehicle. The final sample included 248 encounters at 72 different crossings by 95 participants: 15 drivers (18 encounters); 32 pedestrians (116 encounters); 16 motorcyclists (33 encounters); and 31 cyclists (81 encounters).

3.4.3. Comparing compliant and non-compliant user decision making

The aim of the analysis was to look at compliant versus non-compliant decision making with regard proceeding through the RLX in the presence of a train and associated active warnings (e.g. flashing lights, sounding bells and descending boom gates). A compliant decision was defined as one whereby the road user stopped prior to the RLX when the RLX warnings were activated, as required by the relevant road rules. A non-compliant decision was defined as one whereby the road user proceeded through the crossing after the active warnings had commenced operation. Categorisation of the decision was undertaken based on the entire description provided by the participant and was focused only on compliance in relation to the initial stop / go decision (i.e. not whether a cyclist stopped past the painted stop line, or whether a driver proceeded through the RLX after boom gates had ascended but before flashing lights had extinguished).

Participants' responses to the diary study probes were collated and converted to mean percentage scores by road user group for each of the relevant components of the decision ladder. The trajectories through the decision ladders represent the short cuts taken by users when making the decision to stop or proceed through the crossing (see Figures 3-4).

4. Results

4.1. **Generic decision ladder**

Rasmussen's decision ladder template (see Figure 1) was used to develop a generic model of decision making for a 'stop or go' decision at actively controlled RLXs (see Figure 2). The generic decision ladder includes data from all participants in the sample of this study, and also data from other road users via on road studies, See Salmon et al, In Press). For example, the alert box within Figure 2 shows all of the alerts that participants reported as being used to inform their decision making at the RLX. The purpose of this was to describe as exhaustively as possible how decision making could occur in the RLX context. The decision ladder was developed by two human factors researchers based on a Work Domain Analysis (WDA) of an actively controlled RLX and a range of data regarding road user behaviour at RLXs (i.e., on-road study data, subject matter expert workshop data, and data derived from documentation including standards and guidelines and accident reports; see Salmon et al, In Press).

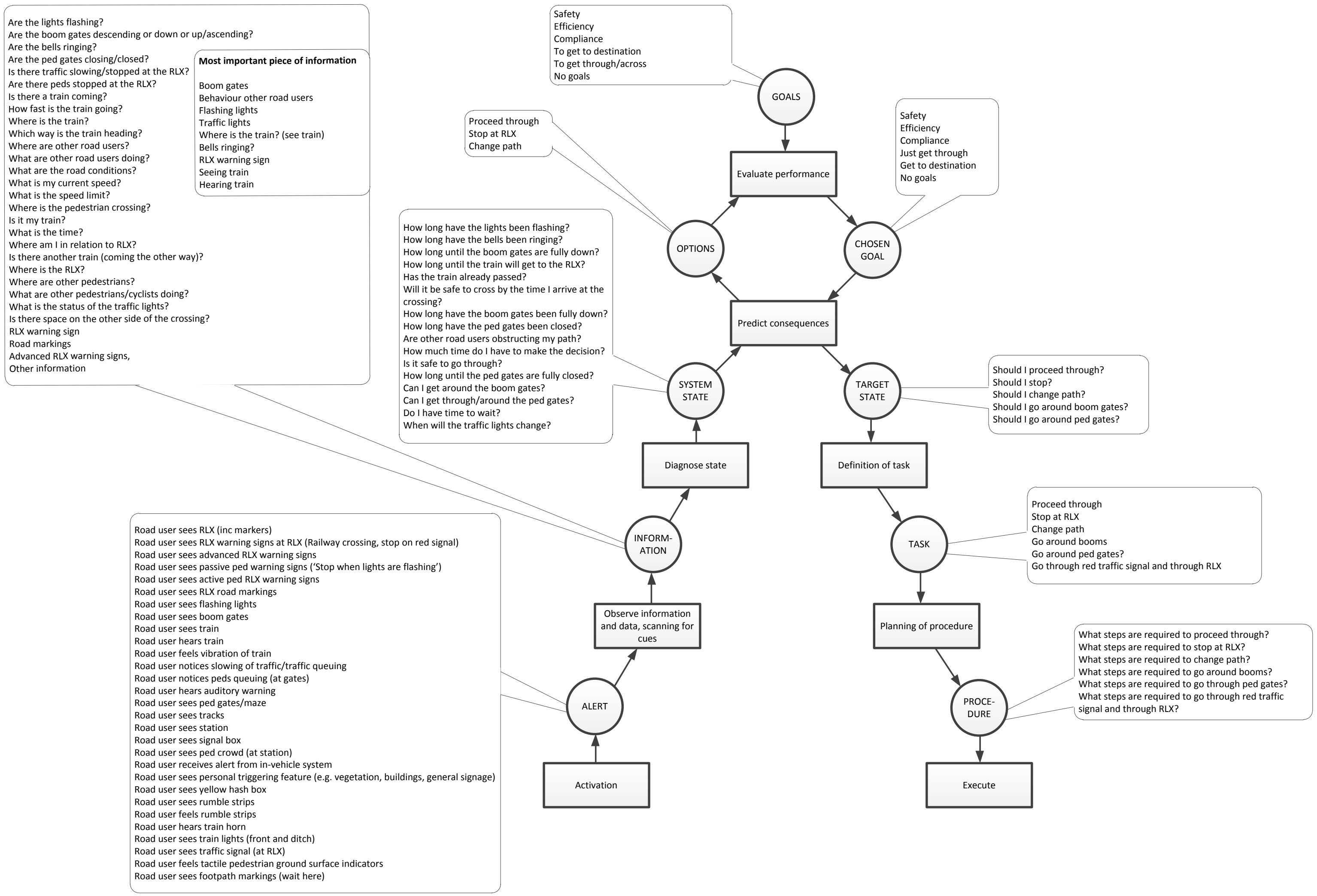

Figure 2. Generic decision ladder for stop or go decision at RLXs. Decision ladder includes data for all participants

4.2. Crossings

In total, 218 compliant crossings were made by 89 road users: 15 crossings by 14 drivers; 97 crossings by 32 pedestrians; 31 crossings by 16 motorcyclists; and 75 crossings by 27 cyclists. Thirty non-compliant crossings were made by 21 road users: 19 crossings by 12 pedestrians; six crossings by five cyclists; three crossings by three drivers; and two crossings by one motorcyclist. Overall 12% of all crossings reported were deemed to be non-compliant, with pedestrians being more likely to violate (37.5%) than drivers (16.7%), motorcyclists (16.1%) and cyclists (6.3%). The following analysis compares the decision making processes adopted by different road user groups both within and between compliance and non-compliance. Since most non-compliant road users were also compliant on other occasions (n = 14), the comparisons are between compliant and non-compliant encounters rather than between compliant and non-compliant road users.

4.3. Goal selection

First, the goals stated by road users were identified and compared. In line with Elix and Naikar (2008) who recommend only one goal per task be represented on decision ladders, where users cited multiple goals, only the first or most important goal (where specified) was included for analysis.

Analysis of the goals chosen by road users when negotiating the RLX revealed that goal choice was consistent with the decision to violate or comply with the active warnings. For compliant encounters, safety was most important for motorcyclists and pedestrians, whereas compliance was most important for drivers and cyclists (see Table 2). Motorcyclists were more concerned than others about having a positive subjective experience, whilst pedestrians were more concerned than other road users with efficiency and getting to their destination. As shown in Table 3, efficiency was generally the most important goal across the four road user groups on non-compliant encounters. Non-compliant pedestrians and cyclists were more concerned than other road users about getting to their destination.

Table 2. *Goals chosen by road users on compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
Safety	19.2%	39.2%	35.5%	38%
Efficiency	6.2%	3.6%	7.9%	10.2%
Compliance	38.5%	26.2%	39.5%	13.9%
Get to destination	18.5%	4.8%	5.3%	24.1%
Get through	13.1%	15.5%	3.9%	11.1%
Positive subjective experience	0	7.1%	6.6%	0
No goals	4.5%	3.6%	1.3%	2.8%
	100%	100%	100%	100%

Table 3. *Goals chosen by road users on non-compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
Safety	33.3%	0	16.7%	5%
Efficiency	66.7%	50%	33.3%	45%
Get to destination	0	0	33.3%	30%
Get through	0	50%	16.7%	5%
No goals	0	0	0	15%
	100%	100%	100%	100%

4.4. Alerts

The alerts that first made road users aware of the upcoming RLX or train are shown in Table 4 for compliant encounters and Table 5 for non-compliant encounters.

Table 4. *Alerts reported by road users on compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
Warning signs	13.3%	6.5%	0	6.3%
Road markings	0	0	1.3%	0
Flashing lights	73.3%	67.7%	34.7%	24%
Boom gates	0	3.2%	8%	7.3%
See a train	6.7%	6.5%	6.7%	7.3%
Hear a train	0	0	1.3%	6.3%
Slowing of traffic	0	12.9%	4%	0
Pedestrians and cyclists queuing	0	0	2.7%	1%
Hears auditory warning	6.7%	3.2%	41.3%	43.8%
Sees pedestrian gates/maze	0	0	0	4%
	100%	100%	100%	100%

Table 5. *Alerts reported by road users on non-compliant encounters*

	Drivers		Motorcyclists		Cyclists		Pedestrians	
	Compliant	Non-Compliant						
Warning signs	13.3%						5.3%	
Road markings							10.5%	
Flashing lights	73.3%	100%	100%		16.7%		5.3%	
Boom gates							5.3%	
See a train	6.7%				33.3%		10.5%	
Hear a train							5.3%	
Pedestrians and cyclists queuing							15.8%	
Hears auditory warning					50%		42%	
	6.7%	100%	100%		100%		100%	

Across all encounters, motorised road users were most frequently alerted to the presence of the RLX by the flashing lights, whilst non-motorised users were alerted most frequently by the auditory warnings. Pedestrians and cyclists were alerted by a wider range of cues than motorised users, particularly when crossing illegally. For example, non-compliant pedestrians were also alerted to the train's approach by other pedestrians queuing, seeing and hearing the train, noticing the road markings, noticing the booms descending, and seeing the warning signals.

There were also some important differences in the types of alerts used by different road user groups across compliant and non-compliant encounters. Compared to when crossing illegally, for example, pedestrians and cyclists who crossed compliantly were more likely to be alerted by the flashing lights and less likely to be alerted by the sight of the train.

4.1. Information

The information that road users relied on when making their decision is presented for compliant encounters in Table 6 and non-compliant encounters in Table 7.

Table 6. *Types of information utilised by road users on compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
Are the lights flashing?	80%	87.1%	74.5%	77.1%
Are the booms descending or ascending?	80%	77.4%	76%	68.1%
Are the bells ringing?	53.3%	51.6%	62.7%	78.4%
Are the pedestrian gates closing or opening?	6.7%		5.3%	24.7%
Is there a train coming?	53.4%	58.1%	64.1%	69.1%
What are other road users doing?		35.5%	24%	13.4%
What are other pedestrians/cyclists doing?			4%	13.4%
What is the status of the traffic lights?	20%	12.9%	21.3%	4.1%
Is there space on the other side of the crossing?		6.5%		
How far can I see along the tracks?		16.1%	1.3%	9.3%

Note. The percentages sum to more than 100% because multiple response options were permitted and participants used multiple features to inform their decision making.

Table 7. *Types of information utilised by road users on non-compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
Are the lights flashing?	100%	100%	16.7%	26.4%
Are the booms descending or ascending?			66.7%	42.2%
Are the bells ringing?			66.7%	52.7%
Are the pedestrian gates closing or opening?			16.7%	5.3%
Is there a train coming?			100%	84.2%
What are other road users doing?			16.7%	5.3%
What are other pedestrians/cyclists doing?				42.1%
What is the status of the traffic lights?			16.7%	
Is there space on the other side of the crossing?	33.3%			
How far can I see along the tracks?			16.7%	31.6%

Note. The percentages sum to more than 100% because multiple response options were permitted and participants used multiple features to inform their decision making.

Table 6 shows that the active warnings were the most important information elements used by all road user groups on compliant encounters. Drivers and motorcyclists were more likely to use the flashing lights than other information elements, whilst cyclists and pedestrians relied most frequently on the status of the booms gates and the auditory warnings. Compared to other road users, pedestrians were more likely to hear the bells ringing and the train approaching, notice the pedestrian gates closing, and to take account of the behaviour of other pedestrians and cyclists. Motorcyclists were more likely than others to use information about how far they could see along the tracks and how much space was available on the other side of the crossing.

Table 7 shows that on non-compliant encounters, the most important information used by drivers and motorcyclists was the flashing lights, whereas for pedestrians and cyclists it was information about whether a train was approaching. Drivers also utilised more information than other road users about how much space was available on the other side of the crossing. Pedestrians and cyclists relied on a wider range of information than other road users, including the behaviour of other road users, how far they could see along the tracks, and the status of the pedestrian gates.

Comparisons across compliant and non-compliant crossing events also revealed a number of important differences within the different road user groups. For non-motorised users, the active warnings were relatively more important information elements on compliant compared to non-compliant encounters whereas the reverse was true for motorised road users. When crossing illegally, pedestrians and cyclists were more likely to use information about whether they could see or not see a train and how far they could see along the tracks.

System state

The system state information accessed by road users when making their decision is presented in Table 8 for compliant encounters and in Table 9 for non-compliant encounters.

Tables 8 and 9 show that on both compliant and non-compliant encounters, all road users accessed information about the status of the boom barriers and whether they felt it was safe to proceed/safe to cross by the time they arrived at the RLX. Pedestrians and cyclists used a wider variety of system state information than motorised users, particularly the amount of time the lights and bells had been operating, information pertaining to the status of the pedestrian gates, and perceptions about how long it would take for the train to arrive at the crossing.

The key differences across compliant and non-compliant encounters were that when making illegal crossings, all road users were more likely to access information relating to the status of the active warnings (booms or bells), whether they felt it was safe to cross/safe to cross by the time they arrived at the crossing, and whether they had time to wait. Pedestrians who crossed illegally were also more likely to consider information relating to the status of the pedestrian gates and how long they thought it would be until the train reached the crossing.

Table 8. *System states used by road users on compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
How long have the lights been flashing?			1.3%	
How long have the booms been fully down?	6.7%	6.5%	13.3%	8.2%
How long until the pedestrian gates are fully closed?				1%
How long have the pedestrian gates been closed?				4%
How long until the train will get to the RLX?			1.3%	7.2%
Will it be safe to cross by the time I arrive at the crossing?				1%
Is it safe to go through?	6.7%	3.2%	2.7%	9.3%
Can I get through/around the pedestrian gates?				1%
Do I have time to wait?			2.7%	1%

Note. Since not all users proceeded up to system state, the percentages in this step do not sum to 100% for all road user groups.

Table 9. *System states used by road users on non-compliant encounters*

	Drivers	Motorcyclists	Cyclists	Pedestrians
How long have the lights been flashing?			1.3%	5.3%
How long have the bells been ringing?			33.3%	21%
How long until the boom gates are fully down?		50%	33.3%	15.8%
How long have the boom gates been fully down?	33.3%		33.3%	10.5%
How long until the pedestrian gates are fully closed?				31.6%
How long have the pedestrian gates been closed?				4%
How long until the train will get to the RLX?			33.3%	15.8%
Will it be safe to cross by the time I arrive at the crossing?		50%		
Is it safe to go through?	33.3%		33.3%	5.3%
Can I get through/around the pedestrian gates?				5.3%
Do I have time to wait?	33.3%		33.3%	5.3%

Note. Since not all users proceeded up to system state, the percentages in this step do not sum to 100% for all road user groups.

4.2. Short cuts through the decision ladder

Short cuts through the decision making process were identified; these are represented in Figures 3 and 4 via the arrows from the left hand side to the right hand side of the decision ladder. Short cuts were taken from the 1) information, 2) system state, 3) target state and 4) task steps in the decision ladder. In other words, road users reported that they made their decision to stop/proceed and how to stop/proceed by taking one of the following pathways:

1) Receiving a piece of information that a train was coming (e.g. seeing the flashing lights);
2) Gathering information and assessing the state of the RLX in relation to the approaching train (e.g. working out that the lights have been flashing for a significant period of time);
3) Gathering information, assessing the state of the RLX, considering their goals, and then working out whether to stop, proceed, or take an alternative route.

The key difference between compliance and non-compliance was that the majority of road users proceeded further along the decision ladder on non-compliant encounters, with most proceeding at least up to system state (66.7% of drivers and cyclists; 63.2% of pedestrians, 50% of motorcyclists), and the remainder up to task. The most frequent pathway on all compliant encounters was to short cut earlier on in the decision ladder from the information step (80% of cyclists, 74.2% of motorcyclists, 73.4% of drivers, and 60.9% of pedestrians); a pathway that was not evident in any of the non-compliant encounters.

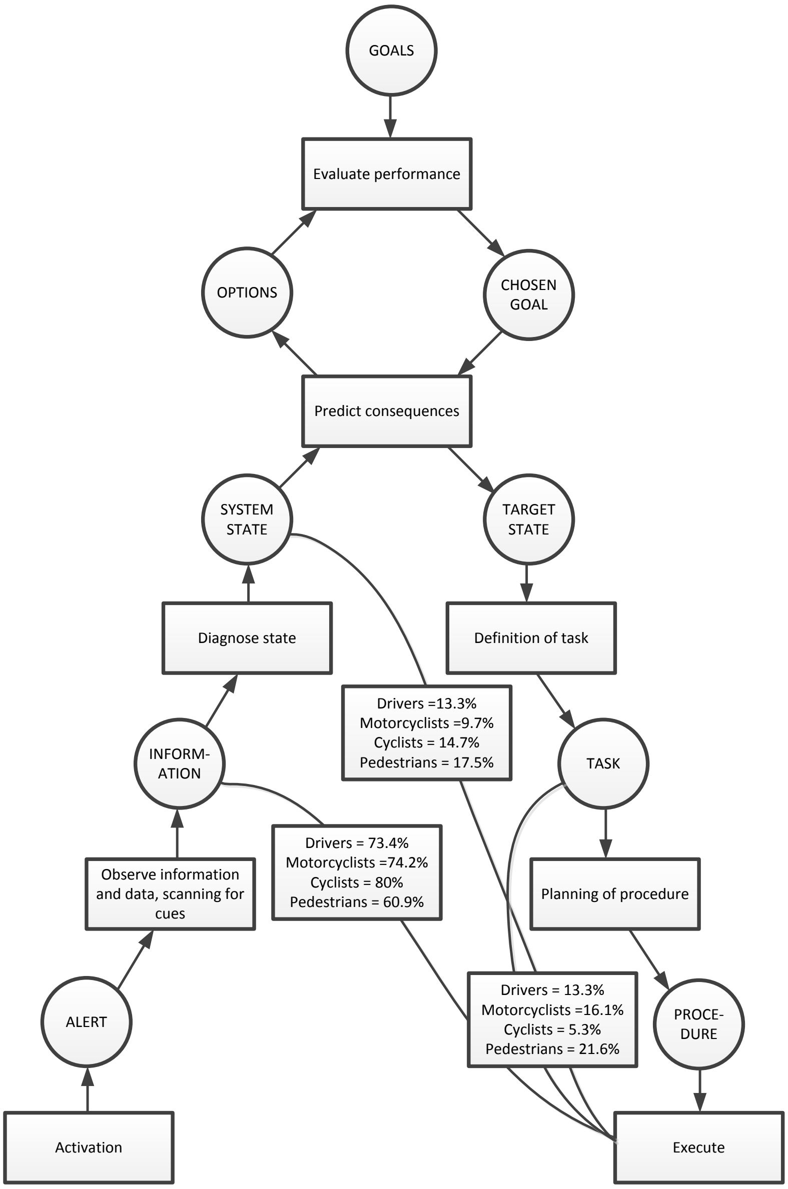

Figure 3. Decision making short cuts taken by road users on compliant encounters.

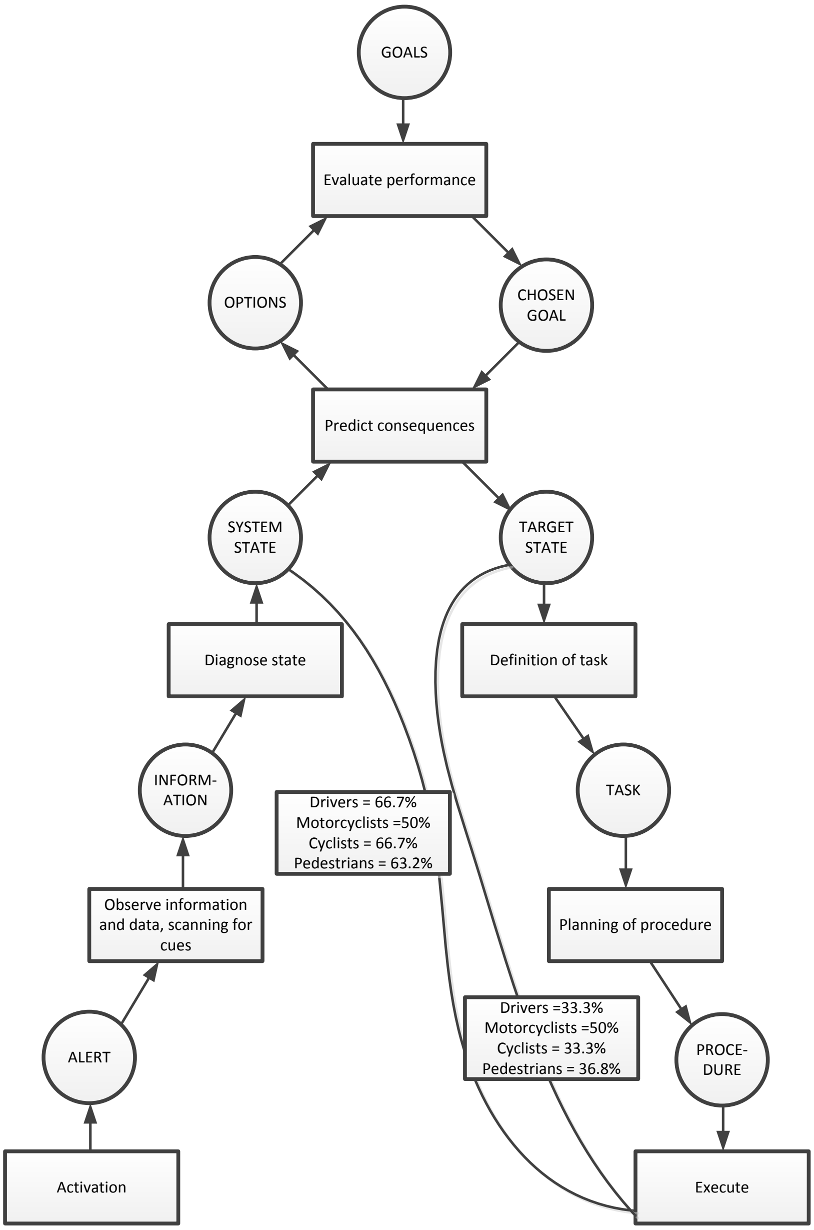

Figure 4. Decision making short cuts taken by road users on non-compliant encounters.

5. Discussion

The study described in this article examined how different road users interact with RLX environments in order to make stop or go decisions when a train is approaching. Rasmussen's decision ladder was used as a theoretical backdrop and the CDM was employed as a means of populating it with data from real RLX scenarios. Overall, the results showed that the decision making processes for different road users vary not only between compliant and non-compliant encounters but also within them; that is, different road users have differing priorities and rely on different alerts and pieces of information when deciding whether to stop or go at different RLX encounters

5.1. Key issues and design implications

The key differences between road users are likely to reflect the fact that the crossing task differs between road users, irrespective of whether the outcome is compliance or non-compliance. Compared to other road users, non-motorised users come into closer contact with the approaching train by virtue of the fact that the pedestrian gates are in closer proximity to the tracks than the boom gates, pedestrians are not restricted by the operation and confinement of a vehicle, and cyclists typically filtered to the front of the traffic queue. It is therefore not surprising that pedestrians and cyclists in this study were more likely to be alerted and informed by the auditory warnings as well as information pertaining to the sight and sound of the train itself. The use of a wider range of cues and information elements by non-motorised users is also consistent with the fact that these road users are more immersed in the RLX environment than motorised road users. Given their need to avoid short stacking over the crossing, it is not surprising that information concerning the behaviour of other motorists and the availability of space on the other side of the tracks was relatively more important to motorised road users.

Within road user groups, the results show that the RLX is used differently when making a non-compliant crossing compared to a compliant one. Since it is physically easier for non-motorised users to cross after the boom/pedestrian gates have closed at most RLXs, it seems plausible that information additional to the active warnings was used to cross the tracks illegally, particularly the sight and sound of the train and sight distance along the tracks. Information about the train's location is less accessible to non-motorised users and likely explains their greater reliance on the flashing lights when making illegal crossings. Violations for these road users only occurred immediately after the lights had commenced flashing, the point at which drivers are generally aware that they can clear the tracks before the boom gates fully close and the train reaches the crossing.

Although the differences between road users reported here are not particularly surprising, they do have implications for safety that remain resistant to current engineering based countermeasures. The propensity for non-motorised users to rely more frequently on cues and information outside of the active warnings suggests that the system provides greater flexibility for these road users to work out whether they can 'safely' beat the train. The use of a wider range of system state information by non-motorised users (i.e., the amount of time the lights and bells had been operating, information pertaining to the status of the pedestrian gates, and perceptions about how long it would take for the train to arrive at the crossing) also explains the relative ease with which the system permits these road users to violate or to consider violating, and likely accounts for the finding that pedestrians were more likely to cross illegally than other road users, including on multiple occasions.

The findings suggest that information about the status of the RLX is considered in ways not intended by designers, even on compliant crossings where the primary goals were safety or compliance. The design question raised by these findings relates to the extent to which information around the time to arrival of the train should be presented to users; that is, should RLX design aim to support users who may be considering whether to violate or not? Or should design deliberately conceal this information from users in the hope that the uncertainty will restrict non-compliant crossings.

Across all road user groups, the key difference between compliance and non-compliance was that the majority of road users proceeded further along the decision ladder on non-compliant encounters, with most short cutting from system state directly to execution of activity. Decision making along this trajectory is not automatic because all road users considered their options for violating on the basis of the system's state. In contrast, the most frequent pathway on all compliant encounters was to short cut earlier on in the decision ladder (i.e., from the information step directly to execution), a pathway that was not evident in any of the non-compliant encounters. The implication here is that many users have well developed skill-based and compliant responses to RLX warnings. Conversely, the more users are able to gather information which ostensibly supports them in working out whether it is safe to violate, the more likely they are to violate. One approach for increasing compliance is to trigger the short cut from the information step in the decision ladder, and bypass the top portion of the decision ladder so that users are unable to access system state information for purposes other than to comply. In design terms this could include modifying the amount of time and information available to users to consider whether it is safe to cross before the train reaches the RLX. However, this goes against most design principles and may also inhibit other users' decision-making. Consequently, providing more information to support users in making the correct decision when working out whether it is safe to violate seems to be a better approach. For example, this might involve using displays to inform users that it is not possible to beat the train past a certain point.

The analysis of goals showed that, during non-compliant encounters, road users were more likely to select goals that were consistent with their decision to violate. This was particularly the case for pedestrians, most of whom were commuters whose primary goal was to get to their destination and who reportedly did not have time to wait for the train. Interestingly, a larger proportion of motorcyclists and cyclists were motivated on compliant encounters by having a positive subjective experience associated with filtering to the front the traffic queue or using the waiting period to rest. For these road users, the focus was not so much on the status of the RLX but on the experiences that take place on approach to it and how the time was able to be used during the waiting period. A possible means of reducing non-compliance then is to design the RLX environment in ways that will occupy road users' time and/or safely divert their attention away from catching or waiting for the train as the primary focus.

Interestingly, the results of this study showed that a small proportion of users who were compliant on some occasions were also non-compliant on others. These findings appear to support the notion that situational as well as intrinsic factors are influential in the decision to violate or comply, and highlight the value in collecting longitudinal data about both compliant and non-compliant decision making.

While this study has provided novel insights into decision making at RLXs there are some limitations that should be discussed. Derived from a naturalistic study, the data were limited by situational constraints on decision making which change over time and which were not held constant when comparing compliant and non-compliant encounters. For example, the presence of some information (e.g., a closed boom gate) is more diagnostic of an imminently dangerous system state than other information (e.g., flashing lights) because it occurs later in the sequence of warnings and so it might be more likely to lead to compliance. With a larger data set, it may be possible to make comparisons between road users who encounter the RLX at a similar point in the warning sequence. Furthermore, a larger data set might include larger numbers of uncommon behaviours such as car drivers driving around boom barriers, enabling an understanding of the decision making processes associated with such behaviour. Alternatively, different methods could be used to gather such data such as critical decision method interviews with road users who have engaged in past non-compliant behaviour at RLXs.

5.2. Conclusion

Overall, the results of this study suggest that the differences in decision making processes across RLX encounters appear to be a function of both the type of road user and whether or not a violation is being committed. These findings are not particularly surprising; however their implications for RLX design are critical to promote safety for all road users in line with systems thinking. Current engineering countermeasures such as flashing lights and boom barriers, put there ostensibly to improve safety, are not always effective because of the high level of flexibility afforded by the system for circumvention. A conundrum for designers is whether to restrict the amount of time and information available to users so that it cannot be used in ways unintended by design or provide more information to help users make safe decisions at the point beyond which a violation could prove life threatening. Systems thinking would support the latter approach because it is more likely to consider the safety of all road user groups. However, any new designs will need to be tested carefully to ensure they do not inadvertently introduce decision making and behaviours that are incompatible with safety.

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