

An exploratory comparison of compliant and non-compliant decision making at actively controlled rail level crossings using the decision ladder

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Abstract

Collisions at rail level crossings (RLXs) present an ongoing major challenge for both road and rail safety organisations. Previous research has made little systematic attempt to understand road user decision making at RLXs, with most research relying on observational studies of single road user groups only. In this exploratory study, we applied Rasmussen's (1974) decision ladder (DL) for the first time in the RLX safety context to compare the decision making processes used during compliant and non-compliant encounters at RLXs. The data used to populate the DL was derived from a two-week diary study in which four groups of road users (drivers, motorcyclists, cyclists and pedestrians) described their encounters with actively controlled RLXs when a train was approaching. Ninety-five road users made a total of 247 crossings, 11.7 % of which were non-compliant ($n = 29$). Overall, the decision making processes differed between compliant and non-compliant encounters. On non-compliant encounters road users were least concerned with safety, based their decision making on a much smaller component of the RLX system, and proceeded further along the DL (i.e., considered multiple courses of action). The results of this study may have important implications for RLX designs, but firstly should be validated using larger samples of non-compliant encounters.

Introduction

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 accounted for just under a third of the nation's 601 motor vehicle-train collisions from 2002 to 2012, and 55% of its 92 pedestrian-train collisions over the same period (ATSB, 2012). Although the proportion of crashes at RLXs is relatively low, the emotional and financial burden on society is disproportionately large, incurring an estimated annual cost of approximately \$24.8 million between 1996 and 2000 (Cairney, 2003).

Human factors have been identified as the primary contributors to RLX collisions (e.g. Edquist, Stephan, Wigglesworth & Lenné, 2009; Salmon, Read, Stanton & Lenné, 2013; Tey, Ferreira & Wallace, 2011; Cooper & Ragland, 2008), with driver compliance at boom barrier and flashing light protected crossings ranging from 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) and has been explained in terms of sensory (e.g., misperceptions of train speed and distance) and non-sensory (e.g. expectations, motivations, social norms) factors (Cooper & Ragland; 2008; Yeh & Multer, 2008). Despite these explanations, the factors that influence road users' decisions are still not well understood.

An emerging theoretical approach with potential to advance decision making research at RLXs is the 'systems approach'. The systems approach takes account of human performance in relation to system wide factors which enable or constrain it (e.g., Dekker, 2011). In the RLX environment, system wide factors include both the interactions between different categories of road users (e.g., train drivers, signal operators, pedestrians, cyclists, motorcyclists, car drivers, truck drivers and

other road users) and system components (e.g., infrastructure, the level crossing environment) (Read, Salmon & Lenné, 2013; Beanland, Lenné, Salmon & Stanton, 2013). Despite calls for a systems approach to understanding performance in safety critical domains, (e.g. Read et al. 2013; Beanland et al. 2013; Salmon et al., 2013), the approach has so far had limited application in the RLX context, with most research based on observational studies of single road user groups only (e.g., Tenkink & van der Horst, 1990; Read et al., 2013). This is an important omission because different road users interact with the system in different ways, and factors that impact positively on one group may impact negatively on another group and vice-versa (e.g., Beanland et al., 2013; Cornelissen, Salmon & Young, 2013; Read et al., 2013).

Beanland et al. (2013) were the first to examine the influence of system wide factors on the decision making processes of different road users at RLXs. They found that both the experiences and behaviour at RLXs differ substantially across different road users. The current study extends this earlier work by using a systems analysis framework known as Cognitive Work Analysis (CWA) to compare the decision making processes used during compliant and non-compliant crossing encounters at RLXs.

CWA focuses on the constraints shaping performance within complex sociotechnical systems (Jenkins, Stanton, Salmon & Walker, 2008), and has previously been applied across a range of safety critical domains for various purposes (see Jenkins et al., 2008). CWA uses a template designed by Rasmussen (1974, cited in Vicente, 1999) called the decision ladder (DL) to describe activity analysis in decision making terms. The DL (See Figure 1) 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 DL is concerned with the observation of the current system state, whereas the right side of the DL is concerned with the planning and execution of tasks and procedures to achieve a target system state. The top part of the DL is concerned with option evaluation and goal selection. The DL represents a sequence of information processing steps (Vicente, 1999). Novices, or experts confronted with unfamiliar tasks, typically follow the DL in a linear fashion, relying on rational, knowledge-based behaviour. Expert users typically take shortcuts, relying on rule-based behaviour to carry out familiar tasks (Naikar, 2010). 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 et al., 2008).

The current exploratory study used the DL for the first time in the RLX context to compare the decision making processes used during compliant and non-compliant encounters. The data used to populate the DL was derived from a two-week diary study in which four groups of road users (drivers, motorcyclists, cyclists and pedestrians) described their daily encounters with actively controlled RLXs when a train was approaching.

Method

Participants

Participants were 166 Victorian residents aged 18-71 years ($M=39.9$, $SD = 12.9$). Most participants resided in metropolitan Melbourne (80%), with the remaining 20% from regional Victoria. Participants were recruited through newsletters, local newspapers and mailing lists and websites for motorcycling or cycling interest groups. All participants were required to be at least 18 years of age and 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 and effort. Ethics approval for the study was granted by Monash University Human Research Ethics Committee.

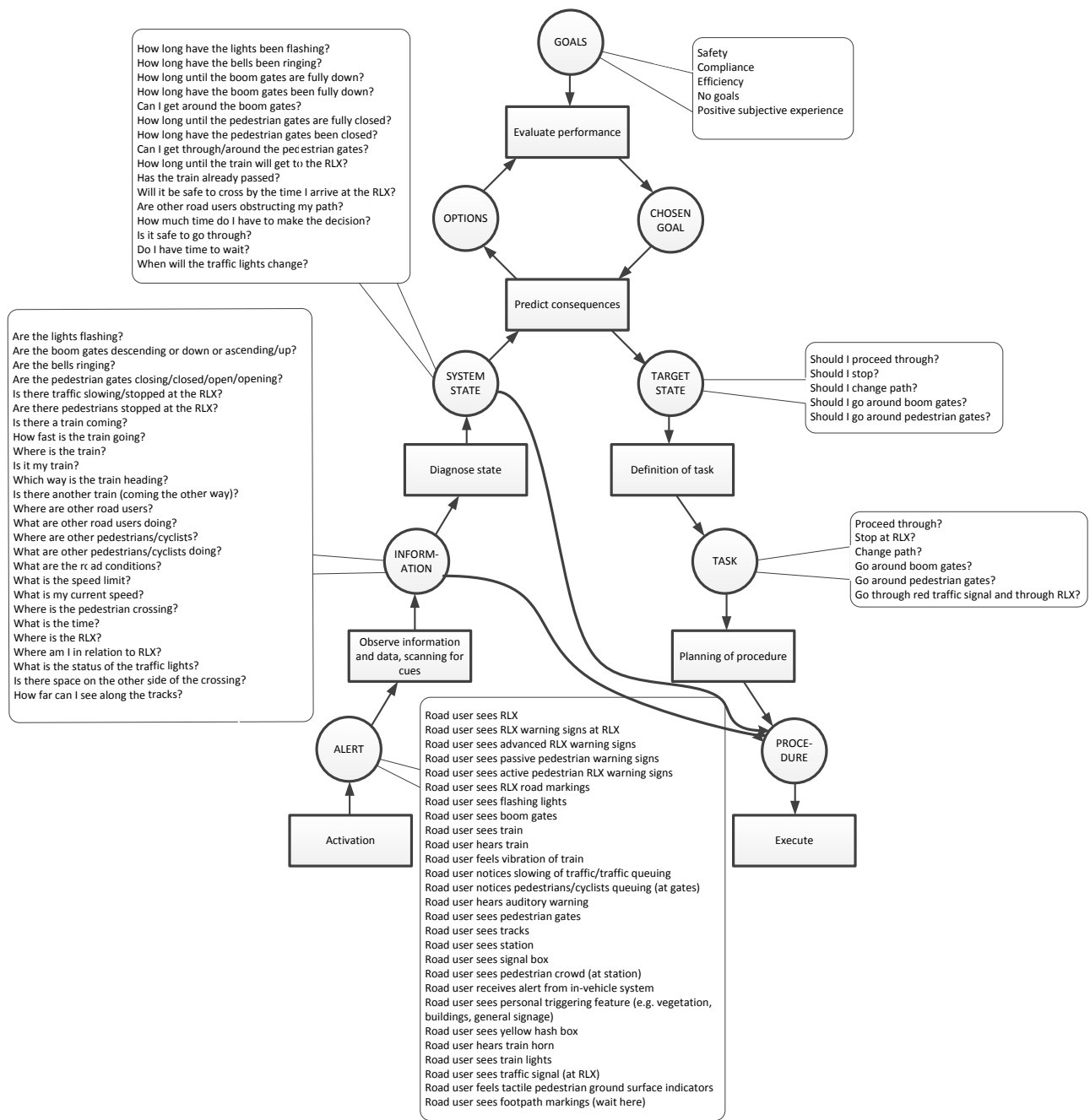


Figure 1. Decision ladder showing possible decision making processes and short cuts at an actively controlled RLX

Demographic questionnaire

Participants completed a short questionnaire at the commencement of the study to record details about age, gender, place of residence, frequency of use of their nominated mode of transportation (number of times per week as measured on a 5-point scale with options for “daily”, “3-4 times per week”, “weekly”, “2-3 times per month”, and “monthly”) and exposure to RLXs (number of hours per week).

Daily diary

Participants completed a daily 'diary' of all RLXs they encountered during a two-week period. They were asked to record 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. flashing lights, boom barriers), participants were asked to record the details of one crossing encounter per day, where applicable. A series of questions based on the critical decision method (CDM) cognitive task analysis interview (Klein, Calderwood & MacGregor, 1989) was used to capture participants' decision making processes, including whether and why they stopped or proceeded through the crossing and the types of information they used to inform their decision. The CDM has been used to model naturalistic decision making in medical settings (Galatner & Patel, 2005), emergency responses (Mendonça, 2007) and driving (Walker, Stanton, Kazi, Salmon & Jenkins, 2009).

Procedure

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.

The DL was used to develop a model of decision making for a 'stop or go' decision at an actively controlled RLX. The purpose of this was to describe as exhaustively as possible how decision making could occur in this context, including all of the ways in which road users could be alerted to the need to make a stop or go decision, all of the information they could use to make this decision, and all of the goals and options available to them. The DL 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. The WDA was developed based on a workshop involving human factors researchers, road engineers, rail safety practitioners, and rail designers. The initial DL was then reviewed and refined through discussion with three additional human factors researchers.

Results

Ninety-three percent of encounters occurred in metropolitan Melbourne, reflecting both the higher proportion of study participants residing there (92.6%: 42.2% from the inner city and 50.4% from suburbia) and the greater frequency of trains running in metropolitan compared to regional areas. Most participants (58.7%) reported that they crossed RLXs daily. With the exception of motorised road users, there was little difference in the proportion of compliant and non-compliant road users who crossed daily (motorised: 63.3% compliant, 100% non-compliant; cyclists: 53.6% compliant; 50% non-compliant; pedestrians: 59.4% compliant, 50.1% non-compliant).

One hundred and forty participants recorded the details of a total of 457 encounters with an approaching train and/or activated warnings. All pedestrians ($n = 35$, 144 encounters), 84% of car drivers ($n = 42$, 135 encounters), 79% of motorcyclists ($n = 31$, 88 encounters) and 75% of cyclists ($n = 32$, 90 encounters) encountered at least one train/active warnings during the study period. Most actively controlled crossing encounters occurred at crossings with boom barriers and flashing lights; active crossings without barriers (flashing lights only) comprised less than two percent of encounters by motorised road users. To ensure consistency in comparisons between road users, only actively controlled crossings with both boom gates and flashing lights were included in the present analysis. 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 also 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 247 encounters at 72 different metropolitan crossings by 95 participants: 15 drivers (17 encounters); 32 pedestrians (116 encounters); 16 motorcyclists (31 encounters); and 31 cyclists (81 encounters).

Analysis of decisions made revealed that the majority of road users complied with activated warnings. A total of 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). A total of 29 non-compliant crossings were made by 20 road users (19 crossings by 12 pedestrians, six crossings by five cyclists, two crossings by two drivers and two crossings by one motorcyclist). For the purposes of the present analysis, drivers and motorcyclists were combined to form a single group of motorised road users, and comparisons were made between compliant and non-compliant encounters for motorised road users, pedestrians and cyclists. Since most non-compliant road users were also compliant on other occasions ($n=14$), the analysis that follows compares compliant and non-compliant encounters rather than compliant and non-compliant road users.

Participants were asked to report their specific goals when approaching the RLX. Figure 2 shows that the goals differed between compliant and non-compliant encounters. Safety was the most important goal for motorised users and pedestrians on compliant encounters (42% and 44.2% respectively), whereas efficiency was the most important goal for both road user groups on non-compliant encounters (75% and 68.5% respectively). On compliant encounters, cyclists were most concerned with compliance (38.7%) whilst on non-compliant encounters efficiency was their most important goal (66.7%). For all road users, safety was relatively less important for all non-compliant compared to compliant encounters, particularly for pedestrians (44.2% versus 10.5%). The reverse was true for efficiency, with the most pronounced difference between motorised user encounters (compliant = 11.1%, non-compliant = 75%).

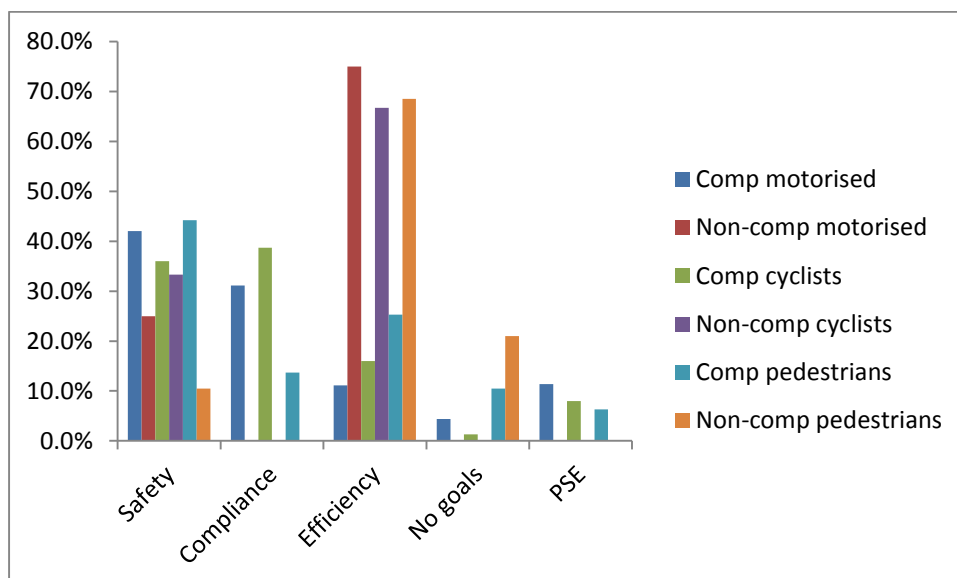


Figure 2. Goals chosen by road users on compliant and non-compliant encounters

Participants were asked to report the alert that first made them aware of the train and/or the activated warnings. Figure 3 shows that the most important alert for both compliant and non-compliant motorised user encounters was the flashing lights (69.6% and 100% respectively). Cyclists and pedestrians across both groups were most likely to cite the bells ringing (cyclists: 41.3%

compliant, 50% non-compliant; pedestrians: 43.8% compliant, 42% non-compliant). Pedestrians were more likely to be alerted by flashing lights on compliant compared to non-compliant encounters (24% versus 5.3%) and the same pattern was evident for cyclist encounters (compliant: 34.7%; non-compliant:16.7%). Seeing a train was cited by a larger proportion of non-compliant compared to compliant pedestrian encounters (10.5% versus 7.3%) and compliant versus non-compliant cyclist encounters (33.3% versus 6.7%).

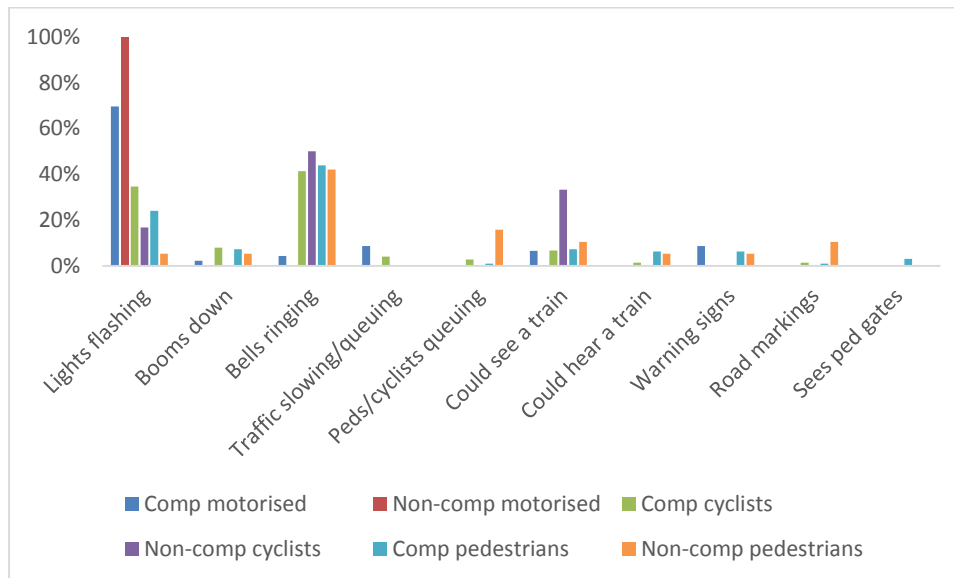


Figure 3. Types of alerts used by road users on compliant and non-compliant encounters

In general, road users were alerted by fewer cues during non-compliant encounters. Whereas motorised road users who crossed illegally relied only on the flashing lights, six alerts were used by motorised road users who made legal crossings. Similarly, cyclists were alerted by eight cues during compliant encounters compared to only three on non-compliant encounters. Pedestrians were alerted by a similar number of cues during both types of encounters (nine versus ten).

Participants reported the information they used when they made their decision to stop or proceed at the crossing. Figure 4 shows that, for all encounters, motorised users were most likely to cite the flashing lights (84.8% and 100% respectively). The bells ringing were most likely to be used during compliant and non-compliant pedestrian encounters (78.4% and 52.6% respectively). Cyclists in both groups were more likely to use information about the booms descending (compliant: 76%, non-compliant: 66.7%). On non-compliant encounters, pedestrians and cyclists were more likely to use information about whether they could see or not see a train than on compliant encounters, and were more likely to use information about how far they could see along the tracks. Motorised users relied on fewer pieces of information when crossing illegally than when crossing compliantly (12 versus 3) and while the same pattern was evident for pedestrians and cyclists, the differences between compliant and non-compliant encounters were not substantial.

Road users identified eight of 16 possible system states. Most assessments pertained to knowledge about whether it was safe to proceed, including the timing of boom and/or pedestrian gate closure and/or predictions about the train's arrival time through the crossing (See Figure 5). With the exception of non-compliant encounters by pedestrians, the most common assessment was 'is it safe to go through?', with road users being more likely to consider whether it was safe to go through on legal compared to illegal encounters (motorised road users: 80% compliant; 50% non-compliant; cyclists: 80% compliant, 50% non-compliant; pedestrians: 52.6%). The most common assessment for non-compliant pedestrian encounters was 'do I have time to wait?' (36.8%).

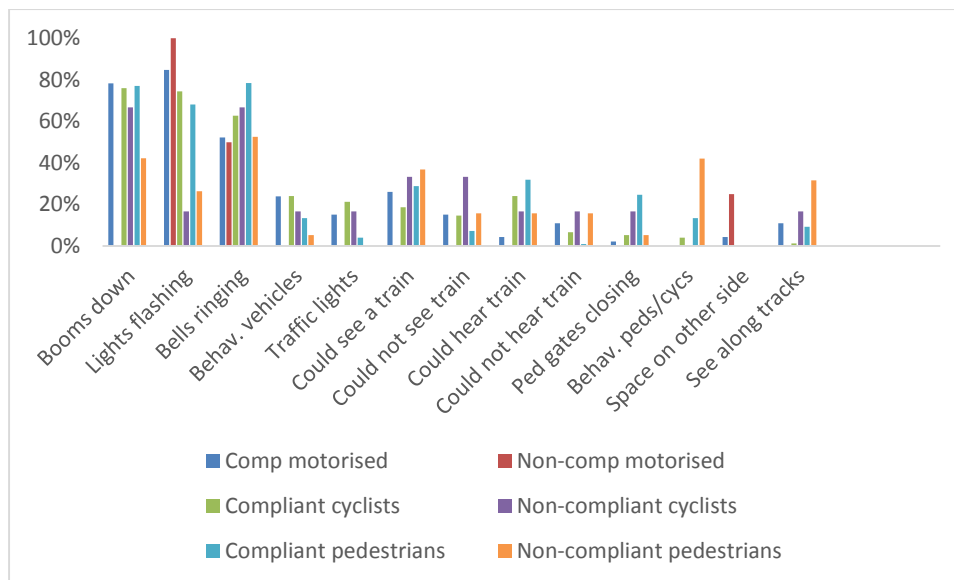


Figure 4. Types of information used by road users on compliant and non-compliant encounters

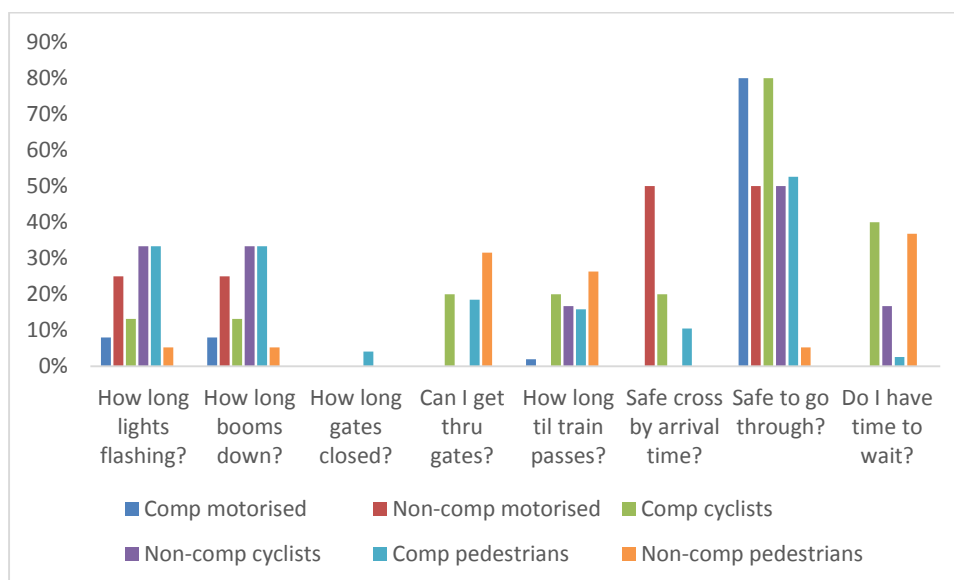


Figure 5. System states identified by road users on compliant and non-compliant encounters

Table 1 shows the pathways through the DL to the behavioural outcome execute. The most frequent pathway on all compliant encounters was to short cut at the start of the DL from information (cyclists: 92.4%, motorised road users: 84.8%, pedestrians: 58.8%). For all non-compliant encounters, the most frequent pathway was to proceeded further along the DL and short cut from system state (cyclists: 83.3%, motorised road users: 50%, pedestrians: 63.2%). For all compliant and non-compliant encounters the next most frequent pathway was to proceed almost to the end of the DL and then take a short cut from task (cyclists: 5.3% compliant, 16.7% non-compliant; motorised users: 15.2% compliant, 50% non-compliant; pedestrians: 22.7% compliant, 36.8% non-compliant). Across all road users, the smallest proportion of compliant encounters proceeded from system state (motorised road users: 2.2%, cyclists: 2.7%, pedestrians: 18.5%)

Discussion

This exploratory study used the DL to examine the decision making processes used by different types of road user groups when crossing compliantly and non-compliantly at RLXs. Although non-compliant behaviour at RLXs is more infrequent than compliant behaviour, the results of this study

were limited by small numbers within each of the non-compliant groups. As such, the following outcomes should be taken as preliminary indications only, and need to be further established with larger samples before reliable conclusions can be drawn.

Table 1. Proportion of different DL trajectories through to execute

	Trajectory		
	Information	System State	Task
Motorised users	C=84.8%,	C=2.2% NC= 50%	C=15.2% NC= 50%
Pedestrians	C=58.8%	C=18.5% NC= 63.2%	C=22.7% NC= 36.8%
Cyclists	C=92.0%	C=2.7% NC= 83.3%	C=5.3% NC= 16.7%

*C=Compliant crossings, NC=Non-compliant crossings

Firstly, there were differences between the types of goals for compliant and non-compliant encounters, with goal choice being consistent with the decision to violate or comply. Efficiency was the most important goal for all road users when illegal crossings were made, whereas safety was the most important goal for motorised road users and pedestrians when crossing compliantly. Compliance was the most important goal for cyclists when making legal crossings.

Secondly, there were some differences between compliant and non-compliant encounters in terms of the number and types of alerts used. On compliant encounters, pedestrians and cyclists were more likely to be alerted by the flashing lights than on non-compliant encounters. In contrast, seeing a train was more important in non-compliant compared to compliant encounters by pedestrians and cyclists. This pattern of results was similar to that found for the types of information used. For pedestrians and cyclists, the active warnings were relatively more important on compliant than 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, whereas the reverse was true for motorised road users. These findings could suggest that making a violation as a pedestrian or cyclist relies more on being able to locate the train than on heeding the active warnings. Consistent with this interpretation, all motorised users who crossed illegally relied only on the flashing lights to alert them to the presence of a train. Unlike motorised road users, pedestrians and cyclists can violate more easily after the active warnings have commenced operation because it is physically easier for them to both see the train and to circumvent the gates.

The results also indicated that on non-compliant encounters road users were alerted by fewer cues and generally utilised fewer information elements than on compliant encounters, a finding that was particularly evident in motorised road users. This is not surprising given that the decision to violate needs to happen quickly; road users may not use all of the information at their disposal, or only that which is most relevant to their decision. The differences between compliant and non-compliant pedestrian encounters, however, were less substantial and may reflect the finding that just over a third of pedestrians who crossed compliantly considered violating at the time. Therefore, it is perhaps not surprising that the amount of information used on both types of encounters for pedestrians was similar.

Thirdly, the types of trajectories through the DL differed in frequency between compliant and non-compliant encounters. Compliant behaviour was typified by a short cut from the information stage

at the start of the DL to the final execution stage; a finding that was consistent across all road users. Decision making along this trajectory is considered to be automatic since no other course of action besides compliance is considered at any stage in the decision making process. In contrast, the most frequent pathway for all non-compliant crossings was to proceed beyond the information stage, with most road users in this category short cutting from system state, and a large proportion short cutting from task. Decision making along these trajectories is not automatic. Road users consider their options for violating on the basis of the system's state and, for those who progress further along the DL, the potential consequences of their intended actions. The results suggest that road users at the system state level based most of their decision making on knowledge about the timing of boom and/or pedestrian gate closure and/or their predictions about the train's arrival time at the crossing.

The present study was limited by situational constraints on decision making which change over time and which were not held constant when comparing compliant and non-compliant crossings. For example, the presence of some information (e.g., 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 a short cut to execution. To address this issue, future research should examine the decision making steps between road users who arrive at the same point in the warning sequence.

Overall, the results of this study suggest that on non-compliant crossings, road users tend to behave automatically, whilst on compliant crossings, road users assess the situation more comprehensively, taking into account a wider range of information about the system's state before committing to crossing. These findings may have important implications for the design of RLXs but firstly need to be validated with larger samples, taking into consideration the methodological limitations described above. Potential design solutions could include those that prevent unsafe behaviour and force compliant behaviour, such as changing the amount of time and information presented to road users attempting to beat the train. However, these need to be considered carefully to ensure that any new designs will not introduce additional problems into the RLX system.

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