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Use of ITS to improve level crossings safety: open issues

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Abstract

Level crossing crashes have been shown to result in enormous human and financial cost to society. According to the Australian Transport Safety Bureau (ATSB) [5] a total of 632 Railway Level crossing (RLX) collisions, between trains and road vehicles, occurred in Australia between 2001 and June 2009. The cost of RLX collisions runs into the tens of millions of dollars each year in Australia [6]. In addition, loss of life and injury are commonplace in instances where collisions occur. Based on estimates that 40% of rail related fatalities occur at level crossings [12], it is estimated that 142 deaths between 2001 and June 2009 occurred at RLX. The aim of this paper is to *(i)* summarise crash patterns in Australia, *(ii)* review existing international ITS interventions to improve level crossing and *(iii)* highlights open human factors research related issues. Human factors (e.g., driver error, lapses or violations) have been evidenced as a significant contributing factor in RLX collisions, with drivers of road vehicles particularly responsible for many collisions. Unintentional errors have been found to contribute to 46% of RLX collisions [6] and appear to be far more commonplace than deliberate violations. Humans have been found to be inherently inadequate at using the sensory information available to them to facilitate safe decision-making at RLX and tend to underestimate the speed of approaching large objects due to the non-linear increases in perceived size [6]. Collisions resulting from misjudgements of train approach speed and distance are common [20]. Thus, a fundamental goal for improved RLX safety is the provision of sufficient contextual information to road vehicle drivers to facilitate safe decision-making regarding crossing behaviours.

Crashes on level crossing in Australia

There are almost 10,000 railway level crossings (RLX) in Australia, which vary with respects to both road vehicle and locomotive traffic flow and the degree of protection afforded to reduce collisions. Railway level crossings, as the name suggests, involve the intersection of a road and railway track at the same level. Collisions occurring at level crossings represent more than 40% of all rail related fatalities in Australia each year [12]. While such collisions only represent 2% of the road toll in Australia [51], they undoubtedly have the potential to have catastrophic consequences and be associated with substantial human and social costs.

A recent report conducted by the Australian Transport Safety Bureau [5] highlighted the extent of rail related collisions and deaths in Australia. Analysing data collected between 2001 and June 2009, the report recorded a total of 355 rail related fatalities in Australia between 2001 and June 2009, at a rate of 41.8 per year. However, this data reflects all rail-related deaths including fatalities involving train occupants, pedestrians [5] and pedal cyclists and is not restricted to incidents occurring at level crossings. Based on the estimate provided by [12] that 40% of rail-related fatalities occur at level crossings, it is estimated that 142 of the rail-related deaths during this period occurred at railway level crossings, at a rate of 16.7 per year. The report continued to reveal that the frequency of collisions between trains and road vehicles has gradually declined over the past decade, from 92 in 2001 to 58 in 2008, at a rate of 74.4 per year [5]. The reduction is largely as a function of development in safety infrastructure and general improvement in road safety initiatives of all kinds (e.g., reductions in drink driving). However the nature of such collisions remains typically severe, with as many as 8% resulting in fatalities [4]. Moreover, the data highlights the influence of human factors in railway level crossing collisions, particularly driver error [5]. Over the period a total of 1,585 driver errors were recorded at level crossing, at a rate of 186.5 per year.

In addition to loss of life, there is also the potential for serious injury to result as a consequence of railway level crossing collisions. In Australia between June 2002 and June 2007, 253 persons were seriously injured in level crossing collisions at an annual average of 50.6 [29]. Moreover, collisions involving road vehicles represented the greatest proportion of injured road users (42.3%). While the rates of death and injury resulting from collisions is substantial, when considering the number of railway crossing fatalities per 100,000 of the population, Australia has a comparatively low rate, 0.02 of deaths in relation to other highly motorised countries such as the United States (0.06) or Finland (0.21) [54].

Not surprisingly, there are enormous economic and social costs associated with collisions at level crossings. In Australia, crashes at level crossings cost an estimated $32 million each year, excluding costs associated with infrastructure losses [10]. Specifically, $10 million of these costs are associated with crashes involving road vehicles. The majority of these costs represent human costs such as impacts on workplace and household productivities and quality of life, emergency services and medical and rehabilitation costs. The costs associated with collisions between road vehicles and trains has been estimated at $180,000 and $430,000 at urban and rural level crossings, respectively, which excludes costs associated with track and train repair [1].

Factors contributing to railway level crossing crashes

In recent years the Safe Systems Approach has achieved increasing dominance as a framework for describing the relationship between the environment, vehicles and driver characteristics in the causation of road traffic crashes. This approach can also be applied to railway level crossing safety [24]. Specifically, the approach describes the connection between the environment (e.g., roads, railway tracks, existing infrastructure), vehicles (both road vehicles and trains) and drivers (of both road vehicles and trains). Environmental contributors include faulty signals, poor lateral sight distances and adverse weather conditions, while vehicle-related factors generally relate to malfunctions, such as a stalled road vehicle situated on a crossing or train malfunction. Finally, numerous driver characteristics, associated with both train operators and road vehicle drivers contribute to the incidence of railway level crossing collisions.

Collisions are rarely the product of a single factor. Rather than occurring in isolation, collisions tend to be the result of the product of a combination of factors. By far the greatest single contributing factor in collisions between road vehicles and trains is that of driver error [6]. While some collisions result due to negligence on behalf of train operators, road vehicle drivers commonly contribute some level of responsibility, largely as a function of the inability for trains to engage in evasive action [24].

There has been a considerable growth in human factors research in the area of railway level crossing safety in recent years. Overall, the evidence suggests that of all driver-related factors, unintentional errors are far more commonplace than deliberate violations [1,5]. Indeed, an Australian study revealed that unintended errors contributed to 46% of all fatal collisions, while intentional errors; such as substance impairment (9%), excessive speed (7%), fatigue (3%) and risk-taking (3%); contributed to fewer collisions [5]. However, this is not to suggest that deliberate violations occurring at crossing do not pose a significant safety risk. Indeed, studies in the United

States have revealed that between 14% and 60% of drivers report that they would ignore lowered gates and flashing lights and circumvent warning infrastructure, even when the oncoming train is clearly visible [20,62]. Moreover, 10% reported experiencing a thrill when attempting to 'beat' a train across the crossing [62].

An investigation of video recordings of Australian RLXs revealed that more than half (59%) of the drivers did not fully stop at passive RLXs. Nevertheless, the majority (41%) of these non-compliant drivers slowed down before crossing the tracks [54]. Two different RLXs with different visibility were investigated and no difference was observed in terms of compliance, which suggests that visibility might not influence driver behaviour at passive crossings. Even with the introduction of advance warning signage, there is no evidence of an increased compliance at passive crossings [59]. At active RLXs Tey and Ferreira [54] observed that driver compliance was 70% with flashing lights and 77% boom barriers respectively. Assessing speed trends while arriving at a RLX shows that drivers tend to be more cautious at passive crossings (18% arriving too fast) than at active ones (23% to 30% arriving too fast). This is likely to be due to drivers scanning for train information, which is readily available at RLXs with active protection systems. This study also analysed compliance once the warning device has been deactivated, which is of interest for "second train collisions". Sixty one percent of the drivers complied, 31% of the drivers crossed before the boom barrier was fully lifted, while 9% of the drivers crossed before the flashing light had stopped.

Overall the compliance level at passive crossings is considerably lower than the one at active crossings. This is due to a reduced driver attention towards passive warning signs. Numerous other driver-related characteristics have also been identified as being associated with increased risk of collisions at railway level crossings. For example, there is consistent evidence to suggest that collisions are more prevalent at crossings with which the driver is familiar [11,41,58,60,63]. This may suggest that drivers become complacent at crossings they regularly use and may take fewer safety precautions when crossing. Familiarity can also induce deliberate risk-taking, as drivers are motivated to violate signals due to learnt expectations, such as anticipated delays [58,60,63] . Conversely, other research has suggested that, for some drivers, the novelty of railway level crossings and various types of safety or warning infrastructure at crossings, can also lead drivers to make unintended errors that increase the risk of collision [31].

The negative impacts of distraction, inattention, hypovigilance, monotony and fatigue have also been highlighted [11,58,63]. Behaviours falling under this category included failing to observe the presence of the train; failing to acknowledge warning signals; mobile phone or car stereo use; internal distraction (e.g., cognitive and emotional processes); and, distraction from other vehicle occupants or events or objects external to the vehicle. In addition, failure to scan the environment has also been investigated, with inadequate scanning behaviour found to be particularly prevalent at passive crossings. Indeed, in an observational study conducted in Australia investigating the scanning behaviour of 264 drivers [60], significant differences were reported between behaviour at active (35% of drivers looked in both directions, 32% in one direction and 33% did not look in either direction) and passive crossings (rates were 20%, 25% and 55%, respectively).

Other characteristics of railway level crossing collisions include the fact that up to 70% of collisions occur during the day [11,12], and incidents involving trains colliding into road vehicles are twice as frequent as road vehicles colliding into trains [12]. Significantly more frequent risky behaviour at railway level crossings has also been evidenced among male drivers [1,58,62], individuals reporting more negative expectations and experiences regarding crossings [63] those with inflated perceptions regarding their ability to 'beat the train' [62], and individuals who engage in other types of risky behaviour [58,63]. Finally, it has been consistently found that collisions are more frequent at actively protected crossings [11,20] although collisions at crossings where low road and train traffic volumes, typically due to complacency, are also a significant problem [11].

There are a number of physiological and psychological factors that facilitate the understanding of the incidence of collisions between road vehicles and trains resulting from driver error. Decisions to cross when a train is approaching are based on a number of sensory (e.g., perceptions of train speed and distance) and non-sensory (e.g., expectations, motivations and social norms) factors [20,63]. For a variety of reasons, humans are inherently inadequate at using the sensory information available to them to facilitate safe decision-making regarding crossing behaviour. Specifically, humans tend to underestimate the speed of large objects approaching them due to the non-linear increases in perceived size of the object [7,17,33,35].

As a result, collisions resulting from misjudgments regarding train approach speed and distance are common [20]. These risks are exacerbated by negative expectancies related to train arrival times and scheduling and increased travel time associated with waiting for a train to pass [20,63]. Thus, the perceived benefits of crossing, despite the activation of warning infrastructure or train detection, might outweigh the perceived costs of waiting, motivating the driver to engage in risky crossing behaviours. Passive crossings present a particularly dangerous situation given that drivers must assess the risk associated with crossing based solely on the available sensory and non-sensory information, without the aid of warning infrastructure (e.g., boomgates, flashing lights), which is problematic given the evidence regarding perceptual misjudgements [58].

The safe systems approach is pertinent to the examination of human factors in railway level crossing collisions. Thus, a fundamental achievement for improved railway level crossing safety is the provision of sufficient information to road vehicle drivers to facilitate safe decision-making in regards to crossing behaviours. However, others have argued that the fundamental goal for railway level crossing safety should be eliminating the choice for drivers to cross rather than improving the ability for drivers to utilise sensory information to facilitate safe crossing decisions [20]. Indeed, efforts should focus on eliminating the possibility of violations at crossings or increasing motivations to not engage is crossing violating behaviours [20].

While it is undoubtedly important to understand the reasons drivers commit violations at railway level crossings, it is also critical to understand the factors that contribute to driver compliance. Outline. The four key factors influencing the degree to which drivers will comply with level crossing safety devices and infrastructure: (a) environmental design and engineering characteristics of the crossing, such as infrastructure at the crossing and train engineering; (b) organisational and management aspects of rail systems, such as identification of crossings in need of development, interconnection of signals and the potential for the development of ITS approaches; (c) social and political forces, such as regulations, public education and enforcement; and, (d) driver characteristics, such as driving skill and driving style [63].

Human factors research in the area of railway level crossing safety, taken together with data regarding the incidence, prevalence of, and costs associated with, collisions at level crossings highlights the need for appropriate warning systems and infrastructure. The consistent evidence suggesting the contributing role of drivers suggests that the development of innovative approaches that directly target drivers is particularly promising to improve railway level crossing safety. Indeed, in recent years there has been a rapid growth in the development of a variety of emerging technologies in the area of railway level crossing safety. Before outlining the types of emerging technologies that have been developed, or are currently in development, and reviewing evaluative research regarding their effectiveness, this report will set the tone by providing a brief review of more traditional approaches to level crossing safety.

Emerging ITS technologies for RLX safety

In recent years there has been a rapid growth in the development of emerging technologies which represent a potentially effective approach to improving driver detection of crossings and trains. Emerging technologies fall under the umbrella of active protection given that they provide automated warnings to motorists of the presence of crossing locations and train traffic and typically involve communication from vehicle-to-vehicle (e.g., train to road vehicle) or vehicle to infrastructure (e.g., road vehicle/train to existing warning infrastructure at crossing). A number of technologies are currently being implemented or trialled for the purposes of RLX safety, including: (a) in-vehicle warning systems (e.g. collision avoidance systems); (b) dynamic warning signals (e.g., advanced variable message warning signs and second-train warning signals); (c) automated photo and video enforcement; (d) obstacle detection systems; and, (e) alternative low-cost train detection systems.

In-vehicle warning systems involve the transmission of signals to and from devices fitted to trains, road vehicles and existing warning infrastructure to detect potential conflict situations at RLX and notify the driver through the activation of in-cab signals (visual, audible or both). Such warning mechanisms are supported by cooperative wireless infrastructure such as Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) technology. Research has revealed technological feasibility of such systems, however careful development of design and human factors issues (e.g., system reliability, user-friendly interfaces) are critical [14]. Systems using three-point systems (e.g., train-infrastructure-road vehicle) and representative sounds for alarms (e.g., train horn) have been found to be most feasible [49,50]. While limited evaluative data exists, there is strong promise for such systems to reduce collisions and violations, particularly if combined with collision avoidance systems. A migration path approach to market implementation (e.g., at-risk crossings and priority vehicles targeted first) has been suggested [53]; however GPS systems present a potential opportunity for more widespread implementation.

Dynamic warning signals include warning infrastructure such as changeable message signs or flashing lights used in conjunction with static signing. Examples include dynamic advanced warning signs which present crossing-relevant information to downstream traffic approaching a RLX and second-train warning signals that alert drivers that another train is expected to intercept the RLX a short period after another train has passed. The former have been found to reduce queuing and delay times at RLX [56] and, while RLX crash reductions have been estimated, the relatively low reliance on information presented on such signs detracts from their effectiveness [8]. The latter have been evidenced to reduce rates of crossing violations by up to 36% and are well accepted by drivers [25]. Automated photo and video enforcement have also been implemented at RLX to promote compliance with existing warning infrastructure (e.g., flashing lights, boomgates) through the threat of enforcement. Numerous studies have evaluated the effectiveness of automated enforcement, with estimates suggesting reductions in violations of 34-94% [40,37,38] and collisions of up to 70% [3]. However, poor methodological quality and numerous studies failing to find evidence of effectiveness [3,26] make it difficult to determine whether observed findings represent real effects or the product of confounding factors.

Obstacle detection systems have recently been developed to prevent collisions resulting from the queuing of road vehicles across a RLX. The systems detect the presence of obstructions (via video or radar detection) and inform the train driver or automatically activate preventative steps (e.g., reducing speed of approaching trains). Limited evaluation research exists, although one study suggested that violations can be reduced when the technology is used in conjunction with four-quadrant gates [57]. While some studies report that obstacle detection systems are technologically feasible [48,39], others argue that improving the ability for vehicles to escape crossings would be a more effective approach, given the heterogeneity of required braking distances of trains [18]. Finally, a number of emerging train detection technologies have been developed that provide comparatively less expensive alternatives to traditional systems employing track circuitry, which given their cost are not feasible in rural locations or at low traffic-volume crossings. A number of studies have provided evidence of technological feasibility [18,14]. While these systems have been found to be comparatively less effective than standard approaches they undoubtedly have the potential to produce substantial safety benefits compared to passive protection[46].

Human factors aspects of ITS interventions

Motorist error is a major contributory factor in many road crashes including level crossing collisions. Therefore consideration of the human element is essential when aiming to reduce level crossing collisions with ITS. Embedding new technologies on board vehicles or around RLX will certainly bring useful information that may help human users to be aware of the current situation and evaluate risk level at RLX. Such new technologies should improve users' ability to identify process and comprehend what is happening at the RLX. In other words, the new technologies should provide their users an accurate awareness of the situation when crossing a RLX [47]

There are different type of roadside interventions (e.g. warning lights, warning signs (design, wording), warning lights on the road surface) which could be activated as a train approaches. However it is necessary for them to have high levels of driver acceptability. The perception that such systems are reliable has been reported to be critical, such that false alarms and missed alerts are minimised [21]. To further increase driver acceptability, emerging technologies should reduce the time between warning alarms and train arrival at the crossing [43,44], as well as reduce ambiguity, motivate driver compliance and provide drivers with adequate time to attend to warning signals and react appropriately without being too distracting [36].

To ensure compliance, it is necessary to obtain high levels of driver acceptability of railway level crossing warning devices, such that motorists perceive the system to be reliable and understand the need for the device [1]. Driver acceptability is largely contingent on the perceived credibility of the warning device. The reliability of warning systems is also critical. Obviously, false alarms are likely to decrease the perceived credibility and reliability of warning devices and increase the prevalence of violations and collisions [9,28,4344]. Reliability of alerts is particularly important for in-vehicle warning systems [27]. False alarms can eventuate in instances when technological aspects misinterpret signals, such that alerts may be delivered when vehicles are within certain distances from trains but not at crossings (e.g., when the railway tracks run parallel to the road or at grade-separated crossings). For instance, participants in a driving simulator study responded slower, or completely ignored, warning alerts after receiving false alarms [21,22]. On the contrary, faster response times were recorded after the system failed to alert drivers of potential dangers at the level crossing. Participant surveys revealed that trust was unaffected by the type of unreliable information presented (e.g., false positives versus false negatives) but was directly related to the degree of unreliability.

Another fundamental step towards increased perceived credibility involves reducing the time between warning alarms and train arrival at the crossing [63]. Numerous studies have shown that rates of deliberate violations are greatest at crossings where the time between activation of warning infrastructure and train arrival at the crossing are unnecessary long and inconsistent [13,19,44]. Research has suggested that the optimal timeframe between activation of the warning system and arrival of the train at the crossing is approximately 20 seconds, and that increased violations can be expected beyond that [44] The fact that different trains travel at different speeds increases the difficulty for detection systems to provide constant warning times, and thus systems should attempt to include speed data in the communication of warnings [63,64].

In addition, systems must be developed to avoid over-reliance and subsequent reductions in the performance of protective crossing behaviours, such as monitoring approach speeds and scanning the crossing environment [11]. The SAL0 project in France for a low-cost warning signal at passive RLXs has also studied this issue for systems that are expected to fail such as low-cost warning signals [47].

Edquist et al [24] suggest that human factors principles must be considered, such that warning systems reduce the cognitive and attentional load of the driver and safeguard against mental overload and distraction. [32] highlight the necessary processes that must be achieved in order for emerging technologies to adequately communicate safety messages to drivers. These are: (a) recognition of the display (e.g., variable message sign, in-vehicle heads-up display); (b) comprehension of the message; (c) perceived credibility of the message; and, (d) compliance with the directions communicated in the message. Thus, displays must be salient and messages unambiguous and standardised.

Liability needs also to be addressed when deploying new ITS intervention. A trend is in the development of affordable technologies to improve safety where the need for costly and fail-safe devices cannot be justified. Some legal concerns result from the use such new technologies in Australia. The compliance with current legislation and standards is argued. There is a legal liability issue in the case of such system failing since Accredited Rail Operators are responsible for reducing the risk at railway crossings to a standard of 'so far as is reasonably practicable'. The road safety committee recommends that low cost technologies should only be used for passively protected crossings, the reliability of such devices should not be below the reliability of road based signals and that drivers should be aware that whilst the device might warn for an incoming train, there is an odd chance that it might not [45].

The costs associated with railway level crashes must be balanced with costs associated with the implementation of various approaches to protection. While it might seem intuitive to install active protection at all railway level crossings, this approach is expensive and does not necessarily eliminate the incidence of collisions between road vehicles and trains. Indeed, active protection has been estimated as costing upwards of $300,000. In Australia it has been reported that 64% of the approximately 9,400 railway level crossings are passively protected and 28% actively protected [27]. Moreover, in Victoria in 2009, only 20% of the 1,872 railway level crossings in the state were protected by boom barriers, with an additional 21.5% protected by flashing lights and warning bells, and the majority (57.1%) protected by give way or stop signs [51]. Costs associated with upgrading all passive level crossings in Australia with active protection have been estimated to be as much as $1.8 billion [12,61]. In addition, there are substantial costs associated with maintenance, particularly in regards to the many rural railway level crossings.

Conclusion

The limited research evaluating the impact of emerging technologies is mixed. There is a paucity of studies evaluating the impact of technologies on violations and collisions, with process evaluations investigating technological feasibility more common. Significant research has been conducted to study driver behaviour and responses to various traditional road based interventions at different types of RLX. However there is a lack of research on designing and assessing the combined impacts of new ITS based in-vehicle and roadside RLX interventions on driver behaviour. Moreover, the literature is plagued by methodological shortcomings such as a lack of statistical significance testing, failure to control for confounding variables, inappropriate test site locations and crude data collection methods. There is a desperate need for more rigorous scientific research to establish the impact of various emerging technologies and to support widespread implementation. Such evaluation should at least cover (i) impacts of the intervention on the individual users (ii) determine whether the estimated impacts are large enough to yield net social gains (iii) assess whether the best outcome have been achieved for the money invested.

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