Exactly which combination of these perceptual deficits is likely to increase older drivers' risk of level crossing accidents is purely speculative. Although intuitively one would assume that any perceptual decrement that reduced drivers' ability to detect level crossing hazards would place them at risk, there is currently no evidence available to confirm this.

5.3.2 Cognitive declines

Alongside the age-related vision declines of older drivers, a general slowing of cognitive function occurs as people age. Thus, older drivers are more likely to suffer from slowed information processing and reaction time, reduced selective or divided attention, and reduced ability to integrate speed and distance information.

It is a consistent finding that older drivers are most likely to be involved in collisions when negotiating intersections in complex traffic environments, especially uncontrolled turns across oncoming traffic (i.e. right-hand turns in Australia) (e.g. Clarke et al. 2010; Daigneault, Joly & Frigon 2002; Di Stefano & Macdonald 2003; Langford & Koppel 2006; Mayhew, Simpson & Ferguson 2006; Owsley et al. 1998; Preusser et al. 1998; Strutts, Martel & Staplin 2009; Zhang et al. 1998). For example, over half of the fatal two-vehicle accidents involving older drivers (i.e. over 70 years) occurred at intersections, with the most common reason being 'failure to yield' (Strutts, Martel & Staplin 2009). Similar findings were obtained using 1996–1999 Australian fatality crash data; specifically, 50% of older driver (i.e. over 75 years) fatal crashes were found to occur at intersections, compared to 21% of middle-aged drivers (aged 40–55 years) (Langford & Koppel 2006). Furthermore, the strongest predictor of pass/fail outcomes of older drivers referred for driving testing was negotiating intersections (Di Stefano & Macdonald 2003).

Intersections are complex traffic environments: they involve a great deal of competing visual information and associated points of conflict. To negotiate intersections successfully, drivers must integrate visual information, detect hazards in the presence of distractions, and make decisions, all in a short amount of time, and often at high speeds. All of these tasks are likely to be harder for older drivers, given that their divided attention, mental processing and reaction time, and ability to integrate speed and distance info are more limited (Oxley et al. 2004; Staplin et al. 2001). By extrapolation, this suggests that older drivers may be particularly at risk of collisions at passive railway level crossings, given that they are also uncontrolled intersections, and often require quick decision-making, including estimation of train arrival time, while driving at high speeds.

Older drivers have been shown to have slower reaction and decision-making times, compared to younger drivers, especially when tested in more complex traffic environments (Charlton et al. 2009; Hong, Kurihara & Iwasaki 2008; Horswill et al. 2009; Martin et al. 2010; Ranney & Pulling 1990; Staplin 1995). For example, a recent Australian driving simulator study of 216 drivers found that the older drivers (aged over 65 years) showed significantly longer brake times for unexpected events than younger drivers (Charlton et al. 2009). However, it could not be determined whether this difference was due to more limited physical mobility, or longer cognitive processing time among the older drivers. However, one study that did examine these influences separately found the decreased braking abilities of older drivers were due to longer reaction times rather than longer movement times (Martin et al. 2010). Additionally, the hazard perception latencies of 34 old-old drivers (i.e. 75–84 years) were significantly longer than those of mid-aged (35–55 years) and young-old (65–74 years) drivers (Horswill et al. 2009). Furthermore, these hazard detection age differences were mediated by drivers' visual abilities of contrast sensitivity and peripheral vision (Horswill et al. 2009).

Among 129 Australian older drivers (aged 60–88 years) who were tested on a driving simulator, the cognitive abilities of working memory, decision-making under time pressure, and confidence in high-speed driving were significantly associated with self-reported crashes that had occurred within the past year (Lee et al. 2003).

Additionally, there is evidence that older drivers have difficulty with motion perception, and in particular, in integrating speed and distance information. A study of over 1200 older driver (60+ years) crashes in three UK counties during 1994–2007, where the drivers were at least partially to blame, found that one in five cross-flow right turn crashes were due to the older driver misjudging the speed of the approaching vehicle (Clarke et al. 2010).

Several studies have shown that older drivers rely more on distance estimations in choosing acceptable traffic gaps in which to cross. Thus, they are more likely to choose unacceptable gaps as the speed of approaching vehicles increase (Scialfa et al. 1991; Spek, Wieringa & Janssen 2006; Staplin 1995; Yan, Radwan & Guo 2007). First, 29 regular drivers observed an approaching vehicle on a test track, which was travelling from 24 to 88 kilometres per hour. The older drivers (aged 55 to 74 years) were found to overestimate vehicle speed at the lower speeds, but underestimate vehicle speed at higher speeds (Scialfa et al. 1991). Second, in both field and simulator trials with 79 drivers aged 20 to 91 years, Staplin (1995) asked the drivers to indicate the last possible safe moment to turn in front of an approaching vehicle. As the speed of the approaching vehicle increased from 48 to 96 kilometres an hour, the older drivers (55–91 years) chose shorter gaps, whereas the gap judgments of younger drivers remained more or less the same. Third, Spek and colleagues (2006) examined the responses of40 younger drivers (with a mean age of 24 years) and 40 older drivers (with a mean age of 67 years) on a driving simulator. They found that when drivers were executing cross-traffic turns, the tendency to accept shorter gaps as the speed of the vehicle approaching increased was greater for older drivers. Finally, Yan and colleagues (2007) tested the ability of 63 drivers aged 20 to 83 to conduct uncontrolled left-turns across oncoming traffic on a driving simulator. Overall, the older drivers (56 to 83 years old) chose larger gaps. However, when analysed in more detail, the older drivers only chose larger gaps than the younger drivers at low speeds, and did not increase their chosen gap size at higher speeds, which did not significantly differ from that of the younger drivers. This was especially problematic as the older drivers accelerated and turned more slowly than the younger drivers, and so they were more likely to be involved in collisions.

Furthermore, it seems likely that older drivers' distorted judgments of speed may also be exacerbated by their visual declines. It has been found that when visual contrast is reduced, the speed of approaching vehicles is harder to estimate, and consistently seems slower (Horswill & Plooy 2008). However, this was not examined as a function of driver age.

The tendency of older drivers to underestimate vehicle speed as velocity increases quite obviously has large implications for their ability to negotiate passive level crossings when trains are approaching. Trains are the fastest vehicles that drivers will encounter, travelling at very high speeds of up to 130 km/hour. Underestimating their speed could have deadly consequences. In fact, a panel of 24 Australian level crossing industry experts considered the most important older driver level crossing risk behaviour to be errors in judgment for the time needed to safely traverse crossings, rated as 'important/very important' by 79% of the experts (Wallace 2008). However, to our knowledge, no empirical research has investigated older drivers' perception for vehicle speeds higher than 100 kilometres per hour, or when using (real or computer-simulated) trains. It may be the case that older drivers' speed judgment errors are even greater for approaching trains, but this possibility has not yet been tested. Additionally, it is possible that, given the difficulties integrating speed and distance information, perceptual errors explained by the Leibowitz and looming effects may be more common or pronounced in older drivers(Staplin et al. 2001). However, the little research that has examined these effects has not looked at the influence of driver age (Barton & Cohn 2007; Clark 2010; Cohn & Nguyen 2003; Leibowitz 1985; NTSB 1998b).

5.3.3 Physical declines

As part of the ageing process, the muscles, bones and joints in the body decline. Muscle loss occurs, and joints become less flexible, which may also be compounded by medical conditions such as Parkinson's disease and arthritis. These physical declines may make general driving tasks, as well as negotiating level crossings, more difficult for older drivers (Shaheen & Niemeier 2001; Staplin et al. 2001; Yeh & Multer 2008).

Muscle strength and flexibility, as well as range of motion, are needed for braking and accelerating, as well as more complex steering for manoeuvring around obstacles. Head, neck and torso flexibility are important for searching for hazards, especially looking over one's shoulder when roads approach railway level crossings at an acute angle. Among 656 Victorian older drivers (aged 55–75+), 12% rated their head/neck mobility as fair or poor

(Charlton et al. 2003). Reflexes are needed for reacting quickly to hazards, such as approaching trains (Shaheen & Niemeier 2001; Staplin et al. 2001; Yeh & Multer 2008).Thus, it is plausible that older drivers who experience such physical declines may be less likely to notice approaching trains, or to act quickly enough to avoid a collision. However, there is limited research addressing the contribution of physical mobility to driving performance or crash history.

5.4 Pedestrians

There is even less research on pedestrian behaviour at level crossings than the limited literature on driver behaviour at level crossings. This is a significant omission, given that for all road users involved in level crossing collisions, the likelihood of being killed is much higher for pedestrians than for vehicle drivers or passengers (Illinois Commerce Commission 2005; Lobb 2006; Parliament of Victoria 2008). To illustrate, the literature review by Lobb (2006) identified only 14 articles on train–pedestrian accidents. Furthermore, most of these were broad, and considered illegal level crossing users together with trespassers — those who crossed at illegal places, other than the level crossing.

As pedestrian road crashes are considered to be more of an urban problem (Oxley et al. 2004), it is also likely that pedestrian level crossing accidents are more likely to occur at active crossings, which are located in more built-up areas with a higher flow of pedestrian traffic(Cairney et al. 2002). However, the current Australian statistics are not detailed enough to confirm this possibility.

A number of human factors are relevant to pedestrian violations at level crossings, including, but not limited to, time of day, age, gender, inattention, time pressures, the number of pedestrians present, the influence of alcohol or drugs, mental illness, and thrill-seeking behaviour. Many, but not all, of these human factors are similar to those that apply to vehicle drivers at railway level crossings.

The ATSB conducted a preliminary investigation of the first 18 pedestrian fatalities between 2002 and 2004 to be included on the National Coronial Information System database (ATSB 2004a). In all cases, the crossing signals were working properly, and there was no trace of alcohol or drugs in the train crew's system. Of these 18 fatalities, eight cases involved misjudgment, in six cases the pedestrians were under the influence of alcohol or drugs, and four cases showed a history of mental illness. These fatalities constituted only a small sample, and did not represent the total number of deaths occurring in that period, but only the number that had been processed and loaded onto the coronial database. Thus, the characteristics of these fatalities cannot be considered as representative of all Australian fatalities at level crossings.

Several studies have shown elevated blood alcohol levels in a high proportion of pedestrians killed or injured at level crossings (e.g. Lerer & Matzopoulos 1996; Lobb 2006; Nixon et al. 1985). However, most of these studies included all pedestrian rail accidents, including falls and trespassing, and not just those occurring at level crossings. The presence of drugs or alcohol seems to be more specific to pedestrian–train collisions, as they are not a prominent feature of vehicle–train collisions (ATSB 2002).

In many cases, pedestrians may be aware of an approaching train, and thus may knowingly violate crossing controls. One US study of pedestrian–train collisions in north-eastern Illinois from 2000 to 2004 found that 66% of cases were likely to have resulted from pedestrians ignoring active warning devices (FRA 2008; Illinois Commerce Commission 2005). In many instances, the pedestrian crossings were fitted with pedestrian gates. The researchers concluded that pedestrian warning devices are 'commonly ignored, and easy to circumvent' (FRA 2008; Illinois Commerce Commission 2005). Additionally, a Public Transport Safety Victoria (PTSV) study found that 31% of pedestrians reported crossing the tracks when they knew a train was approaching (Lloyd's Register Rail 2007). Pedestrians may also illegally traverse crossings by going the wrong way through emergency escape gates (designed to let people out who have gotten trapped on the tracks). This behaviour has been documented in observational studies of several Victorian crossings, including Bentleigh, where several pedestrians have been killed (Dickinson, Maddock & Majernik 2010).

Males are more likely to violate pedestrian level crossings. As previously mentioned, males are clearly over-represented in level crossing pedestrian fatalities (ATSB 2004a). Furthermore, 40% of the males surveyed reported they would at least sometimes cross at pedestrian crossings when lights, bells or gates were activated, but no train was visible, compared with 12% of females (Lloyd's Register Rail 2007).

Pedestrian level crossing accidents more often occur in daytime hours. Moreover, the rate of both violations and incidents at Victorian crossings was found to be much higher during the morning 'rush hour' (Lloyd's Register Rail 2007; Spicer 2008). This may suggest that hurrying to catch trains or to get to work or school on time may play a part in deciding to cross illegally. Additionally, among pedestrians surveyed at seven Melbourne metropolitan level crossings, the most common reason given for violating level crossing controls was being in a hurry (Lloyd's Register Rail 2007).Several studies have found that most pedestrians' behaviour, when violating road traffic or level crossing controls, or trespassing on train tracks, seeks to maximise convenience, and minimise delays (Daff & Cramphorn 2006; FRA 2008; Lobb 2006).

Inattention may also be a factor in pedestrian accidents. Almost one in five pedestrians (18%) surveyed at Melbourne level crossings reported they had become unintentionally caught on the tracks when a train was approaching (Lloyd's Register Rail 2007). The most common reasons reported by these pedestrians were being unaware of a train, or a second train approaching, often due to headphone use. Use of mobile phones or MP3 players may divert pedestrians' attention from the crossing, and use of headphones that block out environmental noise may prevent pedestrians from hearing train engine noises and warning horns.

Incidents may also occur at crossings with multiple train tracks, when a pedestrian crosses following the passage of one train, and into the path of a second unseen train that is approaching from the opposite direction. Of the people surveyed at the seven Melbourne level crossings, 16% reported they would at least sometimes cross at level crossings after one train had passed, but controls were still activated (Lloyd's Register Rail 2007). In the Illinois study, the second main contributing factor to pedestrian accidents occurring between 2000 and 2004 was the presence of a second train, which contributed to 18% of accidents (FRA 2008; Illinois Commerce Commission 2005). Additionally, the three fatal pedestrian accidents that occurred at the Bentleigh, Victoria, crossing between 1998 and 2004 all involved the presence of a second train, as well as illegal access to the crossing (Spicer 2008). An analysis of Victorian coroner reports of pedestrian level crossing fatalities found that the 'second train' scenario was often mentioned (Lloyd's Register Rail 2007).

Pedestrian level crossing violations and accidents may be more likely to occur as the number of people present at the crossing increases. Thus, pairs or groups of pedestrians, including school children, or those who have just alighted from a train at a station, are more likely to violate crossing controls. In an observation of a suburban Melbourne level crossing, pedestrians in a group were observed to scan for trains less often than when they were by themselves (McPherson & Daff 2005). The authors supposed this may have been due to pedestrians' reliance on the collective scanning of the group. Additionally, the presence of a greater number of pedestrians was associated with increases in pedestrian level crossing violations at one Nebraska crossing (Khattak & Luo, in press). This effect was observed for both young children (approximately eight years or younger) as well as older pedestrians. A number of Victorian coroner reports from pedestrian level crossing fatalities discussed the fact that people travelling in pairs or groups were more at risk of being involved in an accident — possibly due to diffusion of responsibility, or distraction. In one instance, a child on the crossing failed to notice the train coming while he was turned around to talk to his friend (Lloyd's Register Rail 2007).

Although misjudging train speed may also be an important factor in pedestrian level crossing accidents, no evidence exists to support this possibility. However, there is some evidence to suggest that most pedestrians have a tendency to underestimate road vehicle speed as approaching vehicles are travelling at higher speeds (Dommes & Cavallo 2011; Oxley et al. 2005). Thus, it is possible that the speed of approaching trains, which often travel at higher speeds than road vehicles, is underestimated by pedestrians at level crossings.

Several more specific high-risk groups of pedestrians have also been identified. These include school children and youth, people with disabilities, and the elderly (Lloyd's Register Rail 2007). Detailed information regarding why these user groups are at increased risk at railway level crossings is limited. Instead, the majority of evidence is extrapolated from the literature on pedestrians in general. For example, a recent literature review and report commissioned by the Victorian Government on at-risk level crossing pedestrian groups mostly relied on general pedestrian research to identify high-risk groups (Lloyd's Register Rail 2007). Thus, we cannot be completely confident that these pedestrian user groups are indeed at-risk of being involved in collisions with trains specifically. As a related consequence, there may also be equally or more at-risk pedestrian groups which are as yet unidentified.

5.4.1 School children

Several studies have shown the increased risk of school-age children at railway level crossings. New Zealand data have demonstrated the high proportion of pedestrian occurrences involving school-aged children: during 1996–1997, 50% of train-related fatalities and 40% of injuries involved children aged between 10 and 19 years (New Zealand Health Information Service 1999, in Lobb, Harré & Terry 2003). Additionally, children aged approximately 8 years or less were involved in 25% more pedestrian level crossing violations than older pedestrians at one Nebraska crossing, observed on three occasions over a three-year period (Khattak & Luo, in press). Finally, school children and youth were involved in almost half of the crossing violations at the crossing observed in Bentleigh, Melbourne (Spicer 2008).

There is limited research to suggest why school children may be at increased risk at railway level crossings. However, possible reasons include reduced scanning behaviour, underdeveloped perceptual or cognitive skills, peer influence, impulsivity, and convenience maximising. Much of this information has been gleaned from the broader pedestrian literature, and research on railway trespassers.

From a survey and camera footage of 208 people at a Victorian level crossing, pedestrians in the 12–17-year-old age group showed the worst scanning behaviour, where only just over half looked in both directions, and 11% did not look at all (McPherson & Daff 2005). However, exactly why these children showed such poor scanning (e.g. distraction, low risk perception) was not examined.

It has been hypothesised that primary school children pedestrians (e.g. 5–12 years) are the age group at highest risk of collisions in general (i.e. not specifically at railway level crossings) due to their relatively recently acquired walking independence, coupled with their underdeveloped perceptual, attention and cognitive skills (Congiu et al. 2008). As has been demonstrated with older people, young children are more likely to rely on the distance of approaching traffic, and not the speed, in deciding when it is safe to cross (Congiu et al. 2008; Connelly et al. 1998). This risk is even more evident at younger ages (e.g. 5–8 years) (Congiu et al. 2008; Connelly et al. 1998).

Additionally, underdeveloped attention skills may also contribute to the poor crossing decisions of young pedestrians. Among 44 children aged 4–10 years, younger children were shown to have worse selective and divided attention skills. Furthermore, higher divided attention skill levels were associated with looking for traffic prior to stepping onto the road, and higher selective attention skills were associated with more controlled crossing (e.g. not running) (Dunbar, Lewis & Hill 2001). Similar findings were demonstrated among 83 children aged 6–9 years, where both increasing age and better executive function skills (i.e. selective attention, working memory, and behavioural monitoring and inhibition) were associated with increased scanning behaviour of approaching traffic before initiating crossing of a suburban road (Barton & Morrongiello 2011). Once these executive function skills were controlled for, the age effect became non-significant. Additionally, among 71 children aged 6–10, poorer executive function skills, including working memory and sustained attention, were significantly associated with choosing an unsafe gap in which to cross in front of a computer-simulated approaching vehicle (Congiu et al. 2008).

Thus, it is possible that the cognitive function needed to cross safely may exceed young children's developmental capacity (Connelly et al. 1998). However, it is also possible that age-related factors such as height, and experience with (road or rail) crossings may also play a part in increased risk (Congiu et al. 2008; Connelly et al. 1998). Importantly, none of these developmental capacities have been tested when using approaching trains as stimuli.

5.4.2 Youth

From an analysis of ATSB pedestrian fatality data from 1997 to 2002, 15–19 year old males were found to have the highest proportion of fatalities. As with vehicle driver accidents, males represented a much greater proportion of accidents; over 90% of the fatalities in this age group were male, and more than one-third of all pedestrian fatalities involved 15–29 year old males. Unfortunately, these data were not normalised on a per population basis.

It is likely that a significant proportion of level crossing violations committed by this age group represent intentional risk-taking behaviour. In the PTSV survey, 18-25 year olds and 26–35 year olds were most likely to report intentionally crossing when a train was approaching (Lloyd's Register Rail 2007).

Additionally, the results of one study suggest that youth exercise poor scanning behaviour at pedestrian crossings. In the Victorian level crossing observation, the age group with the second-worst level of scanning behaviour was the 18–30 year old group; only 60% looked both ways along the tracks, and 5% did not look at all (McPherson & Daff 2005).

However, there is little evidence available to suggest why youth are more likely to take risks at pedestrian level crossings. In both studies mentioned above, underlying reasons behind the youth displaying poor scanning and knowingly crossing in front of trains was not examined. Similar influences as those for younger drivers may be at play, including risk-seeking tendencies, an increased confidence in the ability to beat the train, low knowledge of road rules, a low perception of risk or of consequences, and peer influences (Davey, Ibrahim & Wallace 2006; Davey et al. 2008b; Wallace 2008). Unfortunately, there is currently no evidence to either support or refute these possibilities.

5.4.3 People with physical disabilities or mobility aids

Pedestrian rail level crossings can present a significant safety issue for people with physical disabilities or mobility issues, for two main reasons. First, wheels on mobility aids, including wheelchairs and prams, can easily become stuck in the flange gap between the track and the bitumen crossing path (McPherson & Daff 2004). This is especially likely if the bitumen path does not cross the tracks at a 90 degree angle. Second, the bitumen surfaces of the crossing that span the width of the tracks may be cracked, broken or uneven, causing additional tripping points for those who may be already unsteady on their feet (or wheels) (McPherson & Daff 2004). In 2001, two fatal level crossing accidents involving people in wheelchairs occurred in Melbourne within weeks of one another. In both cases, the wheelchair-bound level crossing users were unable to free their chairs from the tracks before the approaching trains arrived.

In the Victorian level crossing survey, the second-most common reason reported for becoming unintentionally caught on the tracks when a train was approaching was requiring earlier warning of an approaching train due to mobility impairment issues (Lloyd's Register Rail 2007). During this survey, several mobility-impaired pedestrians were observed to take up to 30 seconds to complete their crossing, even though it typically took only 25 seconds for the train to reach the crossing after the active warning bells had started (Lloyd's Register Rail 2007).

A distinguishing feature of this high-risk user group is that infrastructure factors (i.e. crossing surfaces), rather than human factors (i.e. inattention), are the primary reason behind their high-risk status (Lloyd's Register Rail 2007). However, it is possible that slower crossing speeds may partly contribute to the infrastructure risk these crossings impose. Additionally, it seems plausible that if level crossings are a particular source of concern for mobility-limited crossing users, they may cross in an anxious or hurried manner, which may only exacerbate their risk of becoming stuck on the tracks. Sadly, this was the case for one of the wheelchair-bound fatalities mentioned above; when the cerebral palsy sufferer's wheelchair became stuck on the crossing, he panicked and lost all muscle control, preventing attempts to free himself (Lloyd's Register Rail 2007; Silkstone 2005).

vehicle driver), age and gender. The FRA also categorises these occurrences according to potential precursors, such as ‘did not look’, ‘misjudged train speed’, ‘inadequate sight distance’,’ influence of alcohol/drugs’, or ‘fatigue’. All of this detail is provided for both collisions and near-misses. Australian level crossing occurrence data collection and research would be greatly improved simply by following the FRA’s example (Cairney 2003; FRA 2006). It is essential that Australian data be categorised at this level of detail, including the same environmental, level crossing, and road user characteristics as the FRA. Any possible precursors to the occurrence, as perceived by the train driver, road user or witnesses, should also be recorded, such as ‘drove around gates’, ‘on mobile phone’ or ‘gaze focused on nearby intersection’. The ITSR checklist discussed earlier is a promising start, but such detailed data collection and categorisation needs to be implemented nationally, and used consistently by train operators.

Given that rail safety regulation and investigation is still being established at a national level, this is an excellent time to be setting up a detailed framework for collecting this type of occurrence data. The changes currently being implemented should be reviewed with these considerations in mind. If needed, the CFF should be expanded to ensure there is scope for recording and categorising the data according to all of these factors. To ensure data accuracy, clear definitions of all categories must be used. Many of the issues plaguing the currently available statistics will continue if clear and uniform national standards and definitions are not put in place, and if a widely accessible national database is not developed.

It must be acknowledged that it can be extremely difficult to determine the possible human factor precursors associated with Australian level crossing occurrences, given that investigators must rely heavily on ‘external’ judgments to determine the mental state of road users, especially when the road users involved are either dead, or untraceable (as is generally the case with near-misses). For this reason, it may be especially helpful to:

- follow-up vehicle near-misses by tracing number plates
- conduct detailed interviews with injured road users
- obtain reports from witnesses closer to the road user than the train driver, including vehicle passengers and fellow pedestrians.

Although doing this would undoubtedly be logistically difficult, the information obtained would be incredibly valuable, and arguably worth the effort.

Near-misses represent an excellent opportunity to gather detailed data on potential precursors of a large number of level crossing occurrences. Thus, it is vital that the definition of a ‘near-miss’ is not only standardised across jurisdictions, but also defined in enough detail so that train drivers are able to determine easily what does and does not constitute a near-miss occurrence. Additionally, train drivers’ reporting of near-miss occurrences must increase. These two issues are clearly symbiotic — if train drivers have greater faith and understanding in the system, they are more likely to engage with it. But only with detailed occurrence information can the definition of what does and does not constitute a near-miss be made clearer.

Headway is being made into improving the definition of near-miss occurrences by QUT, CQU and UQ researchers, who have recently commenced a Rail CRC project that collects occurrence information from locomotive-mounted video surveillance cameras (Wullems & Toft 2011). Specifically, cameras that are mounted on several trains on lines with a high number of occurrences are triggered on approach to the crossing, and take high-speed sampling to enable a detailed picture of occurrences to be analysed. This method circumvents the need to rely on train driver reports, and provides greater detail and more objective information. This information will enable a clearer definition of near-miss occurrences to be developed. By comparing this video information to occurrence reports, factors that may influence a driver’s decision to report particular occurrences as near-miss incidents can be determined. Furthermore, a Safety Data Guidelines Project for the Rail Industry Safety and Standards Board is currently developing guidelines for classifying, recording and reporting near-misses using the existing ON-S1 and OC-G1 frameworks (Naomi Frauenfelder, personal communication). Innovative approaches such as these will enable more high-quality data to be collected.

To improve near-miss incident reporting, definition and categorisation, it may also be worthwhile to work in partnership with train drivers. Obtaining train driver input into improving the reporting framework will ensure that reporting categories are consistent with train drivers' daily experience, easier to understand, and subsequently more likely to be used. By explaining in greater detail exactly what the occurrence data is used for, and how it can benefit rail safety, and in particular the safety of train drivers, it is more likely that train drivers will consider reporting to be important and useful, and do it more often.

Both near-miss and collision data must be accompanied by various types of normalising data, including, but not limited to, per million train kilometres, million crossing vehicles, population, licensed driver, distance travelled, and hours driven. It is incredibly important to know what characteristics are associated with occurrences when controlling for exposure rates, as the currently available Australian statistics do not provide this information. As an example, it has already been determined that a greater proportion of collisions occur during daylight hours. However, there is also greater road vehicle and train traffic during the day, and the available statistics have not taking into account this greater exposure. It is possible that, when exposure is controlled, it may be inherently more risky for road users to traverse level crossings during the night. If this were true, this would have important implications for the use of countermeasures that improve train and crossing conspicuousness at night-time, such as crossing lighting, and reflectors on trains and at crossings. Furthermore, younger drivers spend much more time driving than older drivers. If the exact figures could be controlled for within analyses, it may emerge that younger drivers' higher risk status is simply a result of their greater time spent driving, and so greater opportunity to be involved in an accident (see Caird et al. 2002 for a thorough discussion).

Additionally, separate occurrence statistics need to be generated for specific high-risk user groups. It has often proved difficult to do this simply because the already small sample sizes used meant the loss of statistical power when splitting the sample further. However, if near-miss data were better reported and categorised, this would provide a much larger sample size to split into data groups, without losing appreciable statistical power. Analysing the characteristics of level crossing occurrences among key high-risk user groups may reveal new and important information. For example, there is evidence to suggest that overall, fatigue and drugs or alcohol are not considered important contributors to level crossing accidents. However, it is possible that these factors may play a larger role in occurrences involving heavy vehicles, as discussed in section 5.1.3. By determining which road user groups have collisions at level crossings, and exactly when and where these occur, we may be able to identify and target potential level crossing 'black spots', perhaps better termed as 'black circumstances' (e.g. passive crossings at night-time for younger drivers) (Summala 1996).

These improvements would allow researchers to generate more accurate and detailed information on human factors implicated in Australian level crossing occurrences.

7.2 The ALCAM

The ALCAM is one of the main tools used to identify the risk level of each Australian level crossing, and prioritise them for upgrades. Thus, it is essential that the risk algorithm within the ALCAM is expanded to include more human factor precursors of level crossing occurrences.

Of course, to be able to do this, greater information is needed on the human factors of level crossing occurrences. Once more detailed occurrence data are collected, these should be linked to the ALCAM database, so that the interaction between crossing characteristics and human factors can be examined in relation to level crossing occurrences. In this way, the ALCAM algorithms can be based on evidence, and not just on expert opinion.

Additionally, it would be advantageous for the ALCAM to be able to predict the likelihood of specific outcomes (e.g. night-time collision, heavy vehicle collision), rather than just a collision. This information would enable countermeasures and interventions to be tailored to the specific risk that each crossing presents. By meeting the above two recommendations, this may be achievable.

7.3 Research

The current research on human behaviour at railway level crossings is limited in two important ways. First, very little research has been conducted on road user behaviour at level crossings, and on the effectiveness of potential countermeasures. Second, the scope and quality of much of this research is limited. For example, studies of road user crossing behaviour often only encompass a short time period, which means that only a limited number of violations can be assessed. Furthermore, many intervention studies only assess a short time period following countermeasure implementation, which does not allow their long-term effectiveness to be determined, and may not include appropriate 'control' crossings. Many studies are affected by small sample sizes — either in terms of the number of road users, or the number of crossings assessed. Finally, very little research has been conducted in the Australian context. There is an abundance of research that still needs to be conducted in this area.

There are many ways that this research could be conducted (see Edquist et al. 2009 for a review). For example, researchers could conduct observations at crossings, either by using trained observers, or crossing- or locomotive-mounted video surveillance cameras. An advantage of using trained observers is that members of high-risk user groups (either all members, or those who are seen to violate crossing controls) could be stopped after they have traversed the crossing and questioned regarding their attitudes and behaviour. However, it is time-consuming, and observers may miss important details. Surveillance cameras have the ability to collect a large amount of data that is objective, and can be re-analysed and coded numerous times by different people. However, this kind of technology is expensive, and complex computer algorithms are needed to reduce the large amount of data to a smaller amount that can then be processed by researchers. In both methods, the internal thoughts, attitudes and motivations of the road users must be inferred from their behaviour or facial expressions, and so are likely to carry some degree of error (Edquist et al. 2009).

Additionally, specific road user groups could be surveyed regarding their attitudes, knowledge, intentions and behaviour regarding level crossings. Focus groups with specific high-risk user groups, such as those conducted by QUT researchers, provide an efficient way of doing this (e.g. Davey, Ibrahim & Wallace 2005; 2006; Davey et al. 2008a; 2008b; Wallace 2008). A large number of road users can be accessed through mail or internet surveys. This type of methodology would be ideal for examining whether sensation-seeking tendencies are significantly related to level crossing violations in younger drivers, compared to the wider driving population. However, surveys of attitudes and intentions do not necessarily equate to future behaviour; for example, people may respond in a socially desirable manner, or may never engage in risky level crossing behaviour, despite showing the intention to (Edquist et al. 2009).

In contrast, computer simulator exercises are able to assess the actual behaviour of road users, be it when driving or walking. Such studies would be able to examine factors such as scanning behaviour, hazard perception, gap selection, and reaction and decision-making time of high-risk level crossing users, and how they are associated with the likelihood of being involved in a level crossing collision — either real, derived from crash statistics or self-reports, or computer-simulated. However, these results may also be subject to social desirability bias, where participants behave in the manner in which they think the experimenters are expecting. Additionally, as the consequences of 'crashing' on a simulator are trivial compared with level crossing collisions in reality, there may be les motivation for drivers to exercise completely safe behaviour, such as appropriate scanning. Thus, though computer simulators provide the potential to gain a great deal of information from within highly controlled conditions, it still may not be a completely valid method of assessing road user behaviour.

Crash case control studies that are more commonly used by epidemiologists may also provide important information on the human factor precursors to level crossing incidents (as an example, see Connor et al. 2002). Specifically, all victims of level crossing occurrences in a given population (e.g. Victorian drivers injured at passive crossings in the years 2012–2014) are matched with control drivers who are recruited from the same level crossing sites, and at the same time of day. These two groups (crash victims versus controls) can then be compared in an attempt to determine what precursor factors may significantly discriminate between those involved in level crossing collisions and those who weren't.

Given that all methods have their strengths and limitations, researchers must use several methods to obtain the most detailed and valid picture of behaviour at level crossings as possible. This research must also be multidisciplinary in nature, combining the expertise of human factor scientists, psychologists, epidemiologists, engineers, optometrists and neuroscientists, to name a few. Research generated from such partnerships will provide a more integrated and holistic view of the precursors to level crossing occurrences.

7.3.1 High-risk users

Greater and more detailed research is needed on the behaviour of high-risk user groups at level crossings specifically, rather than on roads in general. Currently, there is a paucity of research examining how the high-risk groups discussed here behave at level crossings. Consequently, any interventions that are based solely on evidence from road users more generally may well be unsuccessful at reducing level crossing collisions.

By taking a risk management perspective, and from examination of the Australian statistics reviewed here, we feel the first research priority is to focus on the behaviour of heavy vehicle drivers. This is because:

- the proportion of heavy vehicle accidents has increased in recent years, and heavy vehicle drivers are disproportionately represented in level crossing accidents given their proportion of all licensed road vehicles
- their accidents are associated with much higher costs
- their driving behaviour may be more easily modifiable and enforced.

One particular area that needs research is the degree to which fatigue may influence driver behaviour at level crossings. Additionally, it is important to determine how heavy vehicle drivers behave at crossings equipped with different levels of control, and if behaviour differs between drivers from transport companies that are subject to different regulatory procedures. This is not to 'point the finger' at particular companies, but to determine which industry-used regulations appear to be more effective at curbing risk-taking behaviour. It is also important to determine the prevalence of perceptual errors in misjudging train speed and distance in heavy vehicle drivers; given that they must decide to cross at passive crossings at great distances from approaching trains, it seems plausible that these types of collisions may be more prevalent in heavy vehicle drivers.

We consider the second research priority group to be pedestrians, given that:

- of all road users involved in level crossing accidents, pedestrians are much more likely to die
- as a result, their accidents are associated with higher costs in relation to lost productivity and medical costs
- there is evidence that pedestrian education campaigns have a higher likelihood of success.

Pedestrians have been neglected in level crossing research, perhaps partly because they represent only a small proportion of level crossing occurrences. Consequently, any research on the behaviour of this high-risk group at level crossings is sorely needed. Observational studies may determine what risky behaviours are most prevalent, and under what conditions (e.g. in groups, in rush hour). It is also important that pedestrians are questioned about their behaviour once they have crossed, as well as about their knowledge of and attitudes towards level crossings, to determine the more distal precursors of their risky behaviour. Detailed demographics should be collected to enable examination of pedestrian subgroups. Furthermore, studies could test pedestrians' cognitive and perceptual skills in areas that are important for safely navigating level crossings, including being able to ignore distracting stimuli and inhibit dominant impulses, and accurate judgment of the speed and distance of approaching trains (either real, or computer-simulated).

Research is needed on many possible human factor precursors. However, as one particular example, there is limited, but promising evidence to suggest that road users may make fundamental perceptual errors in judging the speed of oncoming trains. Thus, much more research is needed on the Leibowitz and looming effects, as this possibility compromises the safety of all road users at passive level crossings. It is also important to determine if these effects are more pronounced among specific groups, such as older drivers (who have greater difficulty in estimating time-to-arrival) and heavy vehicle drivers (who must make crossing decisions when there is greater distance between them and the approaching train). By determining under what conditions, and for which road users, these errors are more likely, we can begin to target these circumstances for intervention. This research should be quite feasible for Australian researchers to conduct with the appropriate computer simulation and eye-tracking equipment.

Additionally, research must examine the more distal precursors of level crossing occurrences. For example, there is evidence that young pedestrians have the worst scanning behaviour of all age groups. However, there is no evidence as to why this might be the case. Interventions that target these groups are unlikely to be successful unless we know why they do what they do.

Researchers at MUARC have recently been awarded a five-year Australian Research Council Linkage grant, part-sponsored by the Victorian Railway Crossing Safety Steering Committee, to study older drivers, which will include driver simulator research. This represents a promising opportunity to include driving behaviour at railway level crossings. It would be relatively easy to include level crossings within the simulated drives, which has already been done using the same simulator by other MUARC researchers in more general driving populations (Lenné et al. 2011; Rudin-Brown et al. 2010). The researchers could examine the ability of older drivers, relative to the general driving population, to detect and react quickly to approaching trains at passive crossings, by assessing reaction time, looking behaviour, time-to-arrival judgments, for example. This research would be the first to test the driving behaviour of older people at level crossings.

The research examining high-risk user behaviour at level crossings that was conducted by QUT researchers (Davey, Ibrahim & Wallace 2005; 2006; Davey et al. 2007; 2008b; Wallace 2008) represents a promising start in determining exactly who is high-risk at Australian level crossings, and tapping the knowledge and attitudes of these high-risk user groups. The use of focus groups was especially good for exploring emerging themes, seeing as there was little research on which to base hypotheses, and ask specific questions. Their findings provide a solid base on which to build further research using larger samples, not only to replicate their findings, but also to ask more detailed questions generated from the knowledge obtained.

As greater research is conducted, more high-risk user groups other than those discussed here are likely to emerge. Furthermore, the high-risk groups identified here need to be broken down into more homogenous subsamples, to determine exactly which level crossing users in these broad groups are at increased risk. For example, the broader road safety research suggests that not all older drivers are at increased risk of being involved in a road accident. Instead, older drivers with specific levels of decline in their UFOV are much more vulnerable, and could be targeted for interventions, such as driver training, or restricted licences. With large samples, this possibility could also be examined in relation to risk at level crossings. In this way, any countermeasures implemented are less likely to stigmatise and penalise all people within a particular group.

8. Conclusion

Examination of the particular combination of human factor precursors that place certain road users at greater risk of level crossing occurrences is an incredibly important area of research, but one that has received little attention. Because of this, there is a great deal of potential for discovering more and improving the safety of these groups, and by association, all level crossing users.

This review represents only the first step to improving level crossing safety by identifying high-risk groups. At the end of this review, there is still little understanding of why the level crossing user groups identified here are at high risk of being involved in collisions. Thus, the next critical step forward is to move beyond identifying particular groups, and towards uncovering their specific risky level crossing behaviours. Further to this, we need to know why high-risk groups behave in such risky ways.

Greater research, be it in the form of field observations, focus groups and questionnaires, or driving simulation tests, for example, must be conducted with large and representative groups of heavy vehicle drivers, older drivers, younger drivers and pedestrians. Many pertinent research questions have been suggested here, but these represent only the start of the detailed enquiry that is needed.

Until we do this, we will have little success of targeting these groups, and reducing their high-risk behaviour, and likelihood of injury or death.

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Appendix 1 – Annotated bibliography

Key references that discuss human factor precursors associated with high-risk users and level crossing collisions

Reference	Importance	What was done	What was found
Human factors precursors relevant to level crossing accidents			
Clark 2010	***	Tested 10 males' speed estimates of computer-simulated cars and trains, which varied in approach speed	Participants underestimated the speed of the computer-simulated trains, relative to the cars. The most pronounced effect occurred at a starting distance of 120 metres away, where the train and the car were perceived to be travelling at the same speed, when in fact the train was travelling 20 kilometres/hour faster.
Wigglesworth 2001	**	A review of Wigglesworth's human factors level crossing research	Most collisions at passive level crossings occur during daylight hours. Most fatal accidents were attributable to human overload rather than a deliberate breach of regulations. Crossings located near complex intersections with much visual clutter may divert road users' attention from level crossings. 57% of drivers showed identical head movements at both active and passive level crossings, suggesting that many drivers do not distinguish between the two types of crossings. 86% of Victorian level crossing fatalities occurred within one mile of the drivers' home addresses.
High-risk user groups			
Dommes & Cavallo 2011	**	Examined the crossing decisions of 20 young (20–30 years), 21 young-old (61–71 years) and 19 old-old (72–83 years) pedestrians at a computer-simulated road, and correlated these with cognitive and visual abilities	The old-old pedestrians took significantly longer than the other pedestrians to cross the simulated road. Old-old pedestrians made a greater number of unsafe crossing decisions at approach speeds of ≥ 50 kilometres/hour. Processing speed visual attention and time-to-arrival estimates significantly declined with age. All of these cognitive variables significantly predicted unsafe crossing decisions, and considerably reduced the independent effect of age.
Arnold et al. 1997	**	Surveyed 638 Australian heavy vehicle drivers in states that were not subject to driving hours regulations	38% of drivers reported exceeding 14 hours of driving in a 24-hour period; 20% reported getting less than six hours sleep prior to their last journey; and 14% reported nodding off at least occasionally while driving.
Borowsky, Shinar & Oron-Gilad 2010	**	Tested the hazard perception skills of 21 young-inexperienced (17–18 years), 19 experienced (22–30 years),	Driving experience had little effect on the detection of *actual* hazards (e.g. a lead car braking suddenly). Instead, the inexperienced drivers were less likely to detect *potential* hazards (e.g. following too close to a lead car).

		and 16 older drivers (65–72 years) while they watched traffic videos	
Hatfield & Fernandes 2009	*	Surveyed 89 young (16–25 years) and 110 more experienced (35+ years) drivers outside of NSW motor registries, regarding their driving attitudes, motivations and behaviour	Compared with the older drivers, younger drivers underestimated their risk of driving accidents. Additionally, they reported being less likely to avoid risk in general and experiencing greater enjoyment from risky driving behaviours. Younger drivers tended to focus on the positive rather than negative consequences of these risky behaviours, such as 'blowing off steam', getting to a destination quicker, and thrill-seeking. They also considered these behaviours as more accepted by their peers. Finally, the younger drivers reported a greater likelihood of engaging in such risky behaviours again in future.
Horswill et al. 2009	**	Studied the hazard perception latencies of 22 mid-aged (35–55 years), 34 young-old (65–74 years), and 23 old-old drivers (75–84 years) in response to road traffic videos, and in relation to UFOV, contrast sensitivity and reaction time	The hazard perception latencies of the old-old drivers were significantly longer than those of the other drivers. Furthermore, these hazard detection age differences were mediated by drivers' visual abilities of contrast sensitivity and peripheral vision.
Staplin 1995	**	Conducted field and simulator trials of gap selection in front of oncoming vehicles with 79 drivers aged 20 to 91 years	The 24 older drivers (55–71 years) had slower reaction times than younger drivers. As the speed of the approaching vehicle increased from 48 to 96 kilometres an hour, the older drivers chose shorter gaps, whereas the gap judgments of younger drivers remained more or less the same.
Lee et al. 2003	*	Tested the cognitive abilities of 129 older Australian drivers (60+ years) using a driving simulator, and correlated results with self-reported retrospective crash history	The cognitive abilities of working memory and decision-making under time pressure, and confidence in high-speed driving, were significantly associated with the drivers' self-reported crashes that had occurred within the past year.
Barton & Morrongiello 2011	**	Assessed the executive function skills and crossing behaviour, next to an actual road, of 83 child pedestrians (6–9 years)	Age and executive function skills (i.e. selective attention, working memory, and behavioural monitoring and inhibition) were positively associated with increased scanning behaviour of approaching traffic before initiating crossing of a suburban road. The effect of age was no longer significant once these executive function skills were controlled for.

High-risk user groups <u>in relation to level crossings specifically</u>			
Davey, Ibrahim & Wallace 2005; 2006; Davey et al. 2007; 2008a; 2008b	***	Conducted focus groups with three key high-risk level crossing user groups: older drivers (*n* = 43); younger drivers (*n* = 53); and heavy vehicle drivers (*n* =26)	Train drivers considered heavy vehicle drivers to show the greatest amount of risky behaviour at level crossings. They also felt that younger drivers regularly engage in high-risk behaviours at level crossings. Train drivers and heavy vehicle drivers considered that factors relating to heavy vehicle size and speed jeopardised their safety at level crossings. Both of these groups considered that some heavy vehicle drivers engaged in wilful risk-taking behaviour. Younger drivers often had poor knowledge of level crossing rules, and a low perception of risk or consequence for violating controls.
Lloyd's Register Rail 2007	***	Interviewed 216 pedestrians at seven Melbourne level crossings, and identified high-risk groups at pedestrian crossings from an analysis of existing literature, and Victorian coroner reports	Identified school children and youth, the elderly, and people with mobility issues as high-risk users. <u>Survey results</u>: 31% of pedestrians reported crossing the tracks when they knew a train was approaching. 16% reported they would at least sometimes cross at level crossings after one train had passed, but controls were still activated. 40% of the males surveyed reported they would at least sometimes cross at pedestrian crossings when lights, bells or gates were activated, but no train was visible, compared with 12% of females. The rate of both violations and incidents at Victorian crossings was found to be much higher during the morning 'rush hour'. The most common reason given for violating level crossing controls was being in a hurry. 18% of pedestrians reported they had become unintentionally caught on the tracks when a train was approaching.
McPherson & Daff 2005	**	Observed the scanning behaviour of 208 pedestrians at a Melbourne level crossing. The age-brackets that pedestrians belonged to were estimated by observers	Pedestrians in a group were observed to scan for trains less often than when they were by themselves. Pedestrians in the 12–17 year age group showed the worst scanning behaviour, where only just over half looked in both directions, and 11% did not look at all. The 18–30 year old group showed the second-worst level of scanning behaviour; only 60% looked both ways along the tracks, and 5% did not look at all.

Han et al. 2010	***	Reviewed literature on safety of heavy vehicles at level crossings, including a recent field study of acceleration/ deceleration capabilities of Australian heavy vehicles (Trevorrow 2009)	Heavy vehicle drivers are over-represented in Australian level crossing accidents, compared with the number of licensed heavy vehicle drivers. Because of their large size and weight, heavy vehicles take a long time to stop safely prior to level crossings, and to traverse them when accelerating from rest. Field research has demonstrated that the sight distances provided in the then-current Australian Standards were not adequate for heavy vehicles to traverse crossings safely in some instances, such as B-triples driving on gravel roads. A review of the sight distance requirements specified within the current Australian Standards was recommended.
Staplin 2001	**	Reviewed older driver functional declines, and applied these to driving behaviour at level crossings	Older drivers suffer visual, hearing, cognitive and physical declines that affect their driving ability on tasks that apply to negotiating level crossings safely. These declines include visual acuity, perception of approaching vehicle speed and distance, and reduced neck/torso flexibility, among others.

Note. *** = essential to read; ** = quite important; * = not essential.

Appendix 2 – Potential countermeasures

Discussion of potential countermeasures for high-risk users of level crossings has been deliberately relegated to the appendix section. This is because much more research must be conducted on why certain high-risk groups (e.g. young pedestrians) violate level crossing controls before specific countermeasures that address their risky behaviours may be proposed. Additionally, at a more general level, numerous reports and articles are available that review several potential level crossing countermeasures in great detail (e.g. Caird et al. 2002; Cairney 2003; Cairney, Gunatillake & Wigglesworth 2002; Coleman & Venkataraman 2001; Edquist et al. 2009; Fambro et al. 1995; FRA 2008; Larue, Soole & Rakotonirainy 2010; Parliament of Victoria 2008; Rudin-Brown et al. 2010; STAYSAFE Committee 2004; Wallace, McCusker & Hirsch 2008; Yeh & Multer 2008).

Instead, the following discussion highlights only a small selection of countermeasures that may have particular relevance to the high-risk user groups identified in this review. Many of these countermeasures have little evidence regarding their effectiveness, mostly because they have not been properly evaluated. In fact, there is limited or mixed evidence regarding the effectiveness of most countermeasures at Australian level crossings (see Edquist et al. 2009 for a more detailed discussion). Thus, these countermeasures are not presented here as necessarily having a high likelihood of success, but only as options that warrant further research and evaluation.

Before discussing specific countermeasures, it is important to consider level crossing safety from a risk management perspective. The primary goal of risk management is to completely eliminate the risk by removing it (Hopkin 2010). In the case of level crossing accidents, this would involve grade separation (i.e. installing under/overpasses) or crossing closure. However, the former option is very costly, and the latter is unlikely to be possible for all crossings.

If elimination of the risk is unable to be achieved, then the risk must instead be minimised using the most effective options available within the risk management 'hierarchy of control', such as restricting access, engineering safety devices or warning systems, and administrative controls (e.g. procedures, education) (Hopkin 2010). Given that passive crossings are inherently more risky, as they provide no indication of an approaching train, a third effective option would be to upgrade passive crossings to active control. Most Australian jurisdictions are undergoing a continual process of upgrading passive crossings to active control, with the highest risk crossings (according to various risk indices including ALCAM, as discussed in section 3) prioritised for upgrades. However, it is too expensive to upgrade all Australian passive level crossings in this manner (Cairney 2003; Cairney, Gunatillake & Wigglesworth 2002; Parliament of Victoria 2008).

While the best available control countermeasures should be implemented when possible, such as upgrades to active controls, it may be quicker, cheaper and easier to implement lower order control measures in the meantime (Hopkin 2010). Thus, in relation to level crossing safety, it is also important to consider low-cost warning devices. Although low-cost treatments may significantly reduce accidents, they are unable to completely prevent them, and may not be 'fail-safe'. But there is a compelling argument for providing some level of control at a greater number of crossings, rather than complete control at fewer crossings.

Furthermore, active controls are not fool-proof, and will never be able to prevent all level crossing accidents. Specifically, users that deliberately choose to violate level crossing controls find ways around active controls, such as driving or walking around boom barriers, jumping over locking pedestrian barriers, and illegally accessing the pedestrian emergency escape gates. Therefore, such higher order active control countermeasures must be used in conjunction with other lower order countermeasures, such as education and enforcement.

Short of closure or grade separation, no combination of countermeasures can be completely effective at preventing level crossing accidents. Level crossing accidents generally result from the combination of a number of different factors occurring at a particular point in time, and these particular circumstances can never be entirely predicted or controlled for. Two sad examples are the recent deaths of a family in a vehicle at a Victorian crossing that had just been upgraded with rumble strips one month prior (ABC News 2008; Ross 2008; Wigglesworth

2008c). According to media reports, the driver reported not to have seen the warning signs or noticed going over the rumble strips, and did not notice the approaching train until his wife yelled out. Although speculative, and not able to be confirmed until the impending coronial inquest, perhaps other factors such as fatigue, internal distractions and visibility may have limited the effectiveness of the rumble strips. Additionally, a pedestrian fatality recently occurred in 2010 at the Bentleigh crossing in Victoria, after it had been upgraded with 'second train coming' signs, and locking gates following the death of a pedestrian there in 2004 (Carey 2011; Harris 2011). According to police accounts, the elderly female pedestrian ignored the fully operational active warning signs in order to catch an approaching train, and walked into the path of a second train approaching from the opposite direction.

Increasing the conspicuousness of crossings and trains

Improving the ability of the road user to detect both level crossings and approaching trains at passive crossings may especially benefit older road users with limited perceptual abilities. Several reports are dedicated to improving the conspicuousness of trains and infrastructure at passive crossings, and their specific findings will not be repeated here (interested readers are referred to Cairney 2003; Cairney, Gunatillake & Wigglesworth 2002; Lerner et al. 2002). Some methods of improving the contrast, and so detectability, of crossings and trains include increased crossing lighting, and additional retro-reflective material (which reflects the light from a vehicle's headlights back at the road user) on both train carriages and crossings. There is evidence that the addition of street lights reduces night-time accidents at passive crossings, even when controlling for traffic volume (Walker & Roberts 1975, as cited in Caird et al. 2002). Although Australian standards require level crossing signs to be reflectorised, not all crossings have been upgraded to meet these (Edquist et al. 2009). Reflectorising crossings and trains is relatively low-cost to install, but the retro-reflective material must be especially carefully maintained on train carriages, as dirt accumulates quickly, rendering them much less effective (Caird et al. 2002; Edquist et al. 2009; Yeh & Multer 2008).

Several studies have also examined train lighting, and found little evidence to recommend increasing the train lighting beyond what is already provided on Australian trains, especially as they do little to improve conspicuousness during daylight hours (Cairney 2003; Cairney, Gunatillake & Wigglesworth 2002). According to the 2007 Australian Standard, trains are already required to have powerful ditch and train-mounted lights, so increasing lighting would probably do little to improve conspicuousness (Australasian Railway Association 2009; Standards Australia 2007b). As an additional source of lighting, Wigglesworth (2007) advocated for the use of flashing or rotating lights to be trialled as potential countermeasures for increasing train conspicuousness in his submission to the Victorian inquiry into level crossing safety (Parliament of Victoria 2008). However, several committees have recommended against beacons being fitted, and concluded that given the limited evidence available, more trials of increased train lighting are needed (Parliament of Victoria 2008; STAYSAFE Committee 2004).

However, train conspicuousness and detectability have not been tested for specific high-risk groups, such as older drivers. Thus, it is not known whether increased lighting would increase train conspicuousness for this road user group.

Additionally, a countermeasure that may circumvent the visual deficits of older drivers is rumble strips, or tactile strips fixed to the road surface that provide kinaesthetic and auditory stimuli to the road user as they are driven over. Rumble strips are designed to call a distracted road user's attention to the presence of a level crossing. Rumble strips may also be useful for alerting fatigued drivers. However, the limited evidence available on the effectiveness of rumble strips is mixed. As discussed by Raslear (1996), if drivers do not understand the meaning of the stimuli, the rumble strips may actually distract the road user's attention from the direction of the crossing. Some studies have shown that rumble strips are associated with a reduction in collisions at road intersections, but are limited by extremely small sample sizes and problematic methodologies (Harwood 1993, as cited in Wallace, McCusker & Hirsch 2008). Additionally, there is evidence that rumble strips at level crossings reduce the approach speeds of drivers (Radalj & Kidd 2006; Yeh & Multer 2008). However, although this was taken as evidence that the rumble strips prompted an increase in drivers' alertness, it was not known whether the drivers were actually alerted to the level crossing specifically, and thus undertook greater scanning behaviour. Additionally, for rumble strips that are only installed on the crossing approach sides of two-lane roads, there is evidence that drivers will engage in unsafe behaviour to actively avoid them by swerving into the oncoming traffic lane (Wallace, McCusker & Hirsch 2008; Yeh & Multer 2008). Wigglesworth (2008b) specifically advocated for the use of active (pneumatic) rumble strips that only inflate when a train is approaching. The evaluation of rumbles strips at Australian level crossings is ongoing in several states, including Victoria and Western Australia (Victorian Government Department of Transport 2011).

Alerting road users to approaching trains

Arguably, the most important task for level crossing users is determining when a train is approaching. For this reason, passive crossings are inherently more risky, as the onus is on the road user to detect an approaching train, and to then decide whether it is safe to cross (Edquist et al. 2009; Wigglesworth 2008b). A number of warning devices represent promising approaches to this problem, and are currently being trialled in Australia (Larue et al. 2010; Wullems, in press).

For example, intelligent transport systems (ITS) technologies transfer information between trains, road vehicles and crossing infrastructure regarding the presence of approaching trains. ITS technologies may be particularly useful at crossings where visibility is an issue. They may also be especially useful for heavy vehicle drivers, not only because they are especially vulnerable at crossings with limited visibility due to their slow acceleration and deceleration times, but also because their cabs are more likely to be equipped with the technology needed to receive this information. As one example, Vic Roads, along with industry partners, is currently trialling 'radio break-in' technology that involves transmitters that are fitted to level crossing infrastructure. When a train approaches, the device emits a radio signal that can 'break in' to road vehicle radios within a certain vicinity of the crossing, and warn them of the approaching train (Larue et al. 2010; Victorian Government Department of Transport 2011). The Victorian Department of Transport, together with La Trobe University, QUT and others, has won a grant from the AutoCRC on a three-stage project investigating vehicle-to-vehicle and vehicle-to-infrastructure dedicated short range communication ITS. This project is valued at almost $5 million, which includes a 100 vehicle trial of the technology in 2012 (Spicer 2010).

An important warning device for pedestrian crossings is the 'second train coming' active warning sign, which flashes to alert pedestrians to the presence of a second train approaching on another track. Several versions of these signs have shown significant reductions in illegal pedestrian crossing behaviours in several US studies, including bypassing lowered gates, and attempting to cross between the first and second trains (see Yeh & Multer 2008). They have also been installed and trialled at several crossings in Victoria and South Australia (Daff et al. 2007). However, these signs are not being adopted at other crossings, given that cost–benefit analyses showed that this treatment would not produce savings within the 30-year period estimated (Dickinson et al. 2010). Instead, the authors of this analysis suggested that these signs may be more beneficial to adopt at crossings that are undergoing other upgrades, as the extra infrastructure costs may then be reduced.

Improving the ability to judge time-to-arrival

It stands to reason that if all road users tend to underestimate an approaching train's speed, and therefore underestimate its time of arrival, then interventions are sorely needed that improve their ability to make safe crossings decisions. Interventions that improve people's ability to judge train speed may be particularly helpful for older drivers and pedestrians, given their ability to overestimate vehicle arrival time at high speeds, and also perhaps heavy vehicle drivers, who must make the decision to cross while the train is still some distance away, and appears to be moving slowly.

Recently, Mumbai's Central Railway, together with Final Mile Consulting, implemented and evaluated an intervention designed to counter the Leibowitz and looming effects at a Mumbai railway station that averaged one track death or injury per day, mostly due to trespassing (Dominic 2011; Subramanian 2011). Researchers painted sets of several adjacent railway sleepers yellow, at regular intervals. Thus, the rate at which the yellow sleepers disappeared under the approaching train allowed people at the tracks to make a more accurate judgment of the train's speed. In the year following the intervention, the number of deaths at this crossing decreased by 75%. These interventions have since been trialled simultaneously at seven other Mumbai stations, with similar degrees of success. However, as the researchers also simultaneously implemented two other countermeasures (placing graphic photos by the tracks, and changing the timing and pattern of train horns), it cannot be determined how much of this decrease in deaths was due to the yellow sleepers. Additionally, it is unclear whether this intervention would have such great success in the Australian context, where there are significantly fewer rail accidents, and most occur at level crossings rather than as a result of trespassing. Nonetheless, this countermeasure represents a promising and innovative approach to improving people's ability to judge train speed, and is worthy of further research and evaluation.

It may even be possible to counter a perceptual illusion with another illusion — rather than making road users' decisions more accurate, interventions may instead make them overly cautious, by making the road user perceive the train is approaching faster than is actually the case. This might be achieved by spacing the painted sleepers successively closer and closer together, to give the illusion that the train is speeding up. As an alternative for vehicle drivers who are not afforded as close a view of the tracks as pedestrians, perhaps painted poles or other similar stimuli could be spaced along the track approach. Some rumble strips are designed in this manner, so that even when travelling at constant speed, road users feel as if they are speeding up, and hopefully slow down as a result. Leibowitz (1985) proposed that the perceptual illusions responsible for level crossing occurrences could be used as interventions, but to our knowledge, this possibility has not been tested.

Physically preventing access to level crossings

The half boom barriers that are currently used as active controls in Australia can still be driven around by impatient or sensation-seeking drivers. However, several devices can physically prevent drivers from entering the crossing: four-quadrant gates, extended arm gates and vehicle-arresting barriers block the approach and departure lanes to the crossing, and median and centreline barriers installed along the roadway centreline prevent drivers from crossing lanes to manoeuvre around gates. These devices effectively seal off the level crossing to road users, making them almost impossible to circumvent. Additionally, the development of obstacle detection technology may make it possible for approaching trains to be alerted and even halted if drivers become trapped on the tracks after gates have descended (Khoudour et al. 2009; Larue et al. 2010).

Several US studies have demonstrated the effectiveness of these devices at preventing crossing violations (Coleman, Eck & Russell 2000; Coleman & Venkataraman 2001; Heathington, Fambro & Richards 1989; Hellman, Carroll & Chappell 2007; Khattak 2007; Ko et al. 2007; Saccomano, Park & Fu 2007; US Department of Transportation 2001). For example, initial trials of these devices at one North Carolina crossing found that four-quadrant gates alone reduced crossing violations by 86%, median barriers alone reduced violations by 77%, and when these controls were used in combination, violations reduced by 98% (US Department of Transportation 2001). Additionally, use of longer gate arms at one crossing reduced crossing violations by 84% one year after installation.

The results of these studies seem promising. However, several of these studies were limited by methodological issues: the majority studied only a small number of crossings, some using only single sites, no control sites were used, and many used only a short-term follow-up period. Additionally, it is not known how Australian drivers would respond to these controls. Median barriers are currently used in Australia, and four-quadrant gates are installed at selected crossings in NSW and Qld, but there is no research to suggest the effectiveness of these devices in the Australian context.

Upgrading crossings to this level of control is costly, and they are installed in very few sites internationally for this reason (Caird et al. 2002; Cooper & Ragland 2009). Thus, these types of countermeasures may be better suited for high-volume crossings controlled by two-quadrant gates that have a high rate of violations. These devices are also a cheaper alternative to grade separation, and so could possibly be used in instances where this is being considered (Coleman et al. 2000). Due to the large proportion of accidents that they prevent, cost–benefit analyses demonstrate that they deliver a considerable economic return (US Department of Transportation 2001).

Recently, the emergency gates at two busy Victorian pedestrian crossings were upgraded to further prevent pedestrians from illegally accessing crossings when trains are approaching. The emergency gates close when trains approach, and can be released from the track side to provide an emergency exit for people caught on the tracks. However, these gates were easy to unlock from the wrong side by reaching over the fence, meaning pedestrians could and did open these gates illegally to gain access to the crossing. Mechanical and electromagnetic emergency escape gate latches were installed at Bentleigh and Yarraville stations, respectively, which made it more difficult for people to open the emergency gate from the wrong side. The installation of both gate latches resulted in a significant decrease in pedestrian crossing violations. More specifically, CCTV analysis of over 5000 pedestrians at the Yarraville site showed that gate violations significantly reduced from 30 at pre-installation, to one at post-installation (Dickinson et al. 2010). However, the time period of the post-installation assessment was not specified, so it is not known whether these results represent long-term change. Despite such promising results, cost–benefit analyses showed that the gates do not produce savings within the 30-year period specified by VicTrack, and so there is not a compelling reason for installing them at other sites (Dickinson et al. 2010). However, the latches may possibly prove cost-effective at sites that are already undergoing upgrades, rather than as than when used as a stand-alone upgrade.

Restricting access to crossings

Given that some passive level crossings with limited sight distances are not safe for use by heavy vehicles, all jurisdictions have enforced some form of heavy vehicle restricted access. For example, in Victoria, Queensland, South Australia and Western Australia, road and rail authorities have established permits that certain heavy vehicles (such as B-doubles, or vehicles longer than 26 metres) must obtain before they may traverse crossings, and gazetted routes on which they are allowed to travel (Han et al. 2010).

Preventing queuing and short-stacking

Yellow box markings — yellow grid lines painted across level crossing tracks — were designed to prevent queuing across crossings. These markings have been trialled at crossings in South Australia, Victoria and Western Australia with high incidences of queuing, usually at locations with controlled road intersections nearby, and relatedly, active crossing controls. There is some limited evidence from before and after trials to suggest that the yellow box markings have reduced the incidence of drivers queuing on the crossings, which initially had a high number of queuing vehicles pre-intervention (CPG Australia 2009; Traffix Group 2010). Although these initial reports are promising, greater research is needed to determine the effectiveness of these markings.

Education

Given that many drivers may lack knowledge of the dangers posed by level crossings, and of associated rules and regulations, all of the high-risk user groups discussed here could benefit from greater information on these issues. However, such information has already been offered within state-wide and national advertising campaigns, with limited success (Parliament of Victoria 2008; Wallace, McCusker & Hirsch 2008). More success has been found among targeted education campaigns aimed at pedestrians at level crossings (Lobb, Harré & Suddendorf 2001; Lobb et al. 2003; Sposato, Bien-Aime & Chaudhary 2006). To our knowledge, no Australian advertising campaigns have been conducted that raise awareness of perceptual errors, including the Leibowitz and looming effects. The US-founded Operation Lifesaver has included information regarding these illusions into their written educational material (Biederman 2003; Operation Lifesaver 2011b), but no reports have been found that document its evaluation. Simple but effective computer simulations of these effects (for a good example, see National Transportation Safety Board 1998a), along with information describing these errors, may be worth trialling in Australia.

Additionally, more specific education campaigns that are tailored to particular road users, and that teach safer behaviour, may be more promising options (Wallace 2008). For example, older drivers and pedestrians could be made more aware of their age-related limitations, and trained to self-regulate their driving and crossing behaviour. Such interventions have shown reasonable success for older drivers more generally (Owsley, Stalvey & Phillips 2003). Education programs targeted towards younger drivers could train them to scan level crossings and train tracks, and better recognise the hazard that approaching trains pose.

Enforcement

Enforcement of the safe behaviour of all road users at level crossings could be achieved with the use of surveillance cameras. Akin to the red-light camera technology currently used at many road intersections, cameras are activated at the same time as the active crossing control devices. Drivers in violation of controls can then be issued with fines or demerit points. Enforcement cameras have been very effective at reducing level crossing violations and collisions in the US: a meta-analysis of three studies estimated that enforcement cameras reduced collisions by75%, and were the most effective of the 18 countermeasures studied, short of grade separation (Park 2007; Saccomano et al. 2007).

However, it becomes difficult to determine exactly what constitutes an offence; the 'dilemma zone', or the point immediately following signal activation where drivers are unable to stop safely and so must continue through the crossing, must be fully defined for the level crossing context. Such cameras are currently being trialled and introduced in Australia, including Victoria and Queensland (Department of Transport and Main Roads 2009; Victorian Government Department of Transport 2011).

Additionally, there are several options for enforcing safe driving behaviour among heavy vehicle drivers specifically, which are centred on fatigue management and curbing deliberate violations like not stopping or slowing at passive level crossings, and driving around gates at active crossings.

First, there is the potential for enforcement for heavy vehicle drivers to come from within the road transport industry. A 'best-practice' transport company has systems in place to ensure that rosters allocate appropriate work and rest hours, employees are subject to regular medical checks and random drug and alcohol testing, sufficient accommodation is provided for overnight rest stops, and GPS navigation systems are installed within cabs, for example. Companies that do this have greater accountability over heavy vehicle driver behaviour, including their driving log book records (Department of Transport and Main Roads 2009). Companies that put these systems in place can then be accredited under national Heavy Vehicle Accredited Scheme. Apart from the obvious incentive to transport companies of a lower crash risk, they may also receive lower insurance rates as a result. However, at the time of the Rungoo investigation, it was noted that many road transport companies were not accredited under this scheme (Department of Transport and Main Roads 2009). Perhaps legislating mandatory accreditation of road transport companies would lead to greater accountability, and safer heavy vehicle driver behaviour subsequently.

The Ban Ban Springs case study provides an excellent example of road transport company enforcement of heavy vehicle driver behaviour at level crossings specifically (ARRB Group 2008; Cairney 2008). Following the heavy vehicle level crossing accident at this site in 2006, the driver's mining company implemented a rule whereby all drivers had to stop their vehicles at the crossing for at least three seconds before proceeding. This was enforced by security guard monitoring, and the need to alight from the cab and sign a book located at the crossing. Non-compliant drivers were subject to instant dismissal, or were sent off site if they were contractors. This was a very effective strategy; over a period of three months, non-compliance dropped dramatically from about 30% to virtually zero (ARRB Group 2008; Cairney 2008). Similar procedures could be put in place by other road transport companies, or even government regulators.

Other enforcement options for heavy vehicle drivers include camera monitoring, and GPS satellite navigation (Department of Transport and Main Roads 2009). Several states currently use 'Safe T Cams' that are located on designated heavy vehicle routes, and record the front number plates of heavy vehicles. This information is used to detect violations of speed limits and driving hours, and since implementation, has reportedly resulted in reductions in violations (Department of Transport and Main Roads 2009). Also, in-vehicle satellite navigation monitoring GPS has been trialled and implemented in some jurisdictions (Department of Transport and Main Roads 2009). The in-vehicle units monitor the vehicle's position in time, speed and self-declaration of information. Any violations detected by the system can be sent directly to the relevant road authority. However, this system is currently optional, and not all heavy vehicles are fitted with them (Department of Transport and Main Roads 2009). As a GPS map of all Australian level crossing locations exists, this could be used with GPS tracking equipment to examine violations at level crossings specifically. However, this has not yet been done.

Recommendations

All promising countermeasures need much more thorough research and evaluation to determine their effectiveness at improving scanning behaviour, reducing speed, complying with crossing controls, and improving level crossing safety generally. Researchers should strive to include a number of crossings in their evaluations, including matched control crossings that are not treated with the particular countermeasure. It may perhaps be more advantageous to initially study crossings that are known to have a high level of violations; although findings generated from these crossings may not generalise to all Australian level crossings, the greater number of initial violations will allow a greater 'sample size', and thus greater statistical power with which to detect any significant effects. Furthermore, it may be the case that certain countermeasures are more appropriate for use at 'black spot' crossings. Longer pre- and post-intervention crossing observation periods will also provide a greater 'sample size' of potential occurrences, and will provide a better understanding of the longer term effectiveness of these measures. As with all countermeasure research, very little high-quality research has been conducted in the Australian context. Such research is essential for developing countermeasures that are effective at reducing level crossing violations.

However, there are several particularly important areas of countermeasure research, including further research into perceptual interventions that lessen the Leibowitz and looming effects, further trials and development of various ITS technologies that are able to alert road users to the presence of an approaching train at passive crossings, and enforcement technologies for use within the road transport industry, including GPS monitoring, fatigue countermeasures and enforcement cameras. There is also potential for the 'second train coming' warning signs to be trialled in other jurisdictions. These represent only some of the many promising areas of countermeasure research.