

Table 7. Performance decrements and safety risk associated with using head-up displays

Actions investigated	Navigation and speed maintenance
Actions not investigated	Depends on functions implemented on head-up display Predominantly looking, thinking
Type of distraction	Visual cognitive
Actions investigated	Navigation and speed maintenance
Performance decrements	<i>Increased speed control*</i> (Liu & Wen 2004) <i>Increased steering control*</i> (Liu 2003; Liu & Wen 2004) <i>Reduced RT for hazardous events*</i> (Liu 2003; Liu & Wen 2004) *Compared with conventional or head-down display
Risk	None available

Road Safety Policy & Practice

Vulnerable road users in a Safe System

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Key Findings

- Vulnerable road users tend to be poorly accounted for in Safe System models.
- Safe Systems involve more than just susceptibility to crash forces and forgiving systems.
- Studies of traffic conflicts of vulnerable road users can extend Safe System thinking.

Abstract

Road users such as pedestrians, cyclists and motorcyclists are highly susceptible to crash forces. Yet, while Safe System thinking accords susceptibility to crash forces and a forgiving system as focal principles, the greater vulnerability of these road users is barely recognised in many models of a Safe System. This is a concern of growing importance, given current efforts to increase usage of active travel modes and substantially rising injury rates among cyclists and motorcyclists. This paper explores a selection of research studies aiming to identify relevant factors behind traffic conflicts involving vulnerable road users, as a means to determine appropriate countermeasures particularly those involving infrastructure and vehicle technology. A better understanding of the contextual nature and causes of traffic conflict has much potential to contribute to Safe System thinking and conceptualisations, allowing them to extend beyond their traditional focus on susceptibility to crash forces and systems that are forgiving.

Keywords

Active travel, Cyclists, Pedestrians, Safe System, Vulnerable road users

Introduction

Vulnerable road users, namely pedestrians, cyclists and motorcyclists, constitute the road user groups most susceptible to death and injury from crash forces. The ability of the human body to withstand crash forces, or human physical frailty, is a focal principle in many

conceptualisations of Safe System thinking found in documents such as the *National Road Safety Strategy 2011-2020* (NRSS) (Australian Transport Council (ATC), 2011). The NRSS emphasises two other principles inherent in Safe System thinking: that humans make mistakes, and the need for a ‘forgiving’ transport system.

The NRSS champions its Safe System approach as a holistic one, inclusively catering for all road user groups, without favouring one over another. However, this paper considers that the heightened risk borne by vulnerable road users due to their greater frailty relative to other road users deserves more consideration in many road safety strategies' conceptualisations and accounts of Safe System approaches. In particular, there is a need for improved understanding of what should constitute a Safe System approach that is more accountable to vulnerable road users. This need is of growing importance, given that the Australian Government has committed to increasing levels of active travel, such as walking and cycling (Department of Infrastructure & Transport (DIT), 2013), and that motorcycle riding is currently increasing in frequency (Australian Bureau of Statistics (ABS), 2014).

This paper evolved out of work undertaken for Austroads (Lydon, Woolley, Small et al., 2015), involving reviewing the implementation status of the NRSS (as the NRSS required such a review to be undertaken in 2014). The review was aimed at identifying for road safety decision makers a limited number of new or enhanced road safety initiatives or potential areas for more focussed implementation. During this work, it became apparent to its authors that some concern was being expressed in recent research literature that there should be a more concerted focus on the circumstances and needs of vulnerable road users within Safe System thinking and planning. In particular, while Safe System conceptualisations and approaches rightly stress the need for such a system to be forgiving of human error and crash forces, this needs to be balanced with approaches that aim to minimise, if not eliminate, the potential for conflicts to occur within traffic streams, as traffic conflicts are often especially hazardous to vulnerable road users. Indeed, the Austroads review recommended, as a potential follow-up action, that further research be undertaken to clarify this very point.

This paper is best considered as a discussion emanating from that previous work. Several aspects of Safe System thinking pertinent to vulnerable road users are not discussed, however, (including safe speeds, road law compliance by vulnerable road users, and pedestrian impact protection on vehicles), as these areas were not required focusses for the original work undertaken.

Methods

A selective review of research literature was conducted, chosen for its potential to support a renewed consideration of the place of vulnerable road users within Safe System thinking and planning. Relevant literature was searched using the following databases: *Transport Research International Documentation (TRID)*, Informit Online, ScienceDirect and the CASR library database by using the search terms: vulnerable road user, pedestrian, cyclist, motorcyclist, walking, infrastructure, vehicle technology, vehicle safety, Safe System. The literature search was confined to references from 2012 as the work required for Austroads purposely focussed on identifying new or recent

information. The original search identified 172 research-related items relevant to vulnerable road users. When it became apparent during the NRSS review that there is an emergent view suggesting a need to reconsider the status of vulnerable road users in Safe System thinking, 29 of the items were subsequently chosen for their potential contribution to illustrating the emergent view in more detail.

Increasing travel among vulnerable road users

There is growing recognition, including from the Australian Government (DIT, 2013) that, not only are more Australians undertaking walking and cycling trips more often, but policies of active travel (including workplace health and safety policies) are urging them to do so. Travel survey data show that not only do most Australians walk at some stage during their day, but that almost 4% of journeys to work or full-time study involve walking. In some inner city locations, and in major activity centres, the mode share of walking across all purposes is *much higher than for any other mode of transport* (DIT, 2013, p. 5, emphasis added). Moreover, four out of ten people (43.7%) regularly walk for reasons other than accessing work or study, typically shopping (ABS, 2012). Every day, around 178,500 people cycle to work (representing 1.6% of mode share). As well, around 517,600 ride a bike for other purposes, representing 4.8% of mode share (ABS, 2012).

An indication of increased frequency in motorcycle riding can be gleaned from the motor vehicle registration data collated by the ABS (2014). In 2014, motorcycles comprised 4.4% of all vehicle registrations nationally. However, motorcycle registrations between 2009 and 2014 increased by 25%, which was the highest growth rate over that period out of all types of vehicle, with increases in registrations of light rigid trucks and campervans following in second and third place. The average annual growth rate for motorcycle registrations over 2009-2014 was 4.7%. (ABS, 2014)

The European Transport Safety Council (ETSC) (Adminaite, Allsop & Jost, 2015) has noted the safety implications of increasing engagement in active travel, particularly cycling and walking, but that these safety implications are not necessarily negative ones. Some countries (such as the Netherlands and Sweden) have high cyclist and pedestrian participation rates but with relatively low crash involvement (Adminaite, Allsop & Jost, 2015). Moreover, because of their lower speed and mass, cyclists and pedestrians do not endanger other road users as much as vehicle drivers do. Therefore, the ETSC argues, car drivers who also engage in walking or cycling can, if accompanied by measures to reduce the risks of walking and cycling, increase overall road safety. (Adminaite, Allsop & Jost, 2015)

Vulnerable road users among road fatalities and injuries

Over the past five years in Australia, up to one in five road deaths involved a pedestrian or cyclist. About one in six involved a motorcycle rider or passenger. Table 1 shows the

proportions of fatalities that involved pedestrians, cyclists and motorcyclists (out of all road fatalities), for each 12 month period ending in April, and across 2011-2015, based on data published by the Bureau of Infrastructure, Transport and Regional Economics (BITRE, 2015).

Table 1. Pedestrian, cyclist and motorcyclist fatalities, Australia, 2011-2015

12 months ended April	Pedestrian		Cyclist ^a		Motorcyclist ^a	
	n	%	n	%	n	%
2011	174	13.1	28	2.1	223	16.8
2012	189	14.9	33	2.6	200	15.8
2013	153	11.9	36	2.8	217	16.9
2014	164	14.0	58	5.0	193	16.5
2015	162	13.8	34	2.9	206	17.5

^aincludes passengers (for both cyclists and motorcyclists)

It can be seen in Table 1 that pedestrians accounted for between 11.9% and 14.9% of all road fatalities in Australia during April 2011 to April 2015. Cyclists accounted for 2.1% to 5.0% and motorcyclists 15.8% to 17.5% over the same period. BITRE (2015) also reported that, on average over 2011-2015, pedestrian fatalities declined by 2.8% and motorcyclist fatalities by 3.2%, while cyclist fatalities increased by 10%. Nonetheless, Australian motorcyclists per distance travelled have experienced a fatality rate approximately 30 times that of car occupants, and a serious injury rate 41 times that of car occupants (Johnson, Brooks & Savage, 2008).

Using case data supplied by the National Hospital Monitoring Database (NHMD), which is operated by the Australian Institute of Health and Welfare (AIHW), the Austroads review of the NRSS (Lydon et al., 2015) examined recent rates of serious injuries among cyclists and pedestrians. It found that, while rates of pedestrian serious injuries were gradually declining, rates of injury among cyclists and motorcyclists have been rising dramatically since at least 2001. In 2001, motorcyclists and cyclists accounted for 29% of serious injury cases, rising to 38% in 2010. Moreover, the absolute increase in hospitalised cases involving motorcyclists and cyclists was many times larger than the absolute decline in fatal cases. In fact, the review considered the substantial rise in cyclist and motorcyclist serious injury accounted for the overall rise in serious injury when totalled across *all* road user groups (Lydon et al., 2015).

Further analysis in the Austroads review considered that the upward injury trend among cyclist and motorcyclist cases was “especially steep” for men aged 45 to 64. Also, as might be expected, the rise was much more marked for cases that occurred in on-road traffic than for non-traffic cases, and for cyclists was most marked among residents of major cities than elsewhere (Lydon et al., 2015).

In sum, up to one in five Australian road fatalities involves a pedestrian or cyclist, and up to one in six involves a motorcyclist. Cyclist fatalities and serious injuries, along with motorcyclist injuries, are rising substantially. Such increases dramatically illustrate the greater susceptibility of vulnerable road users to crash forces which, together with the growing participation in walking, cycling and motorcycling, provides a strong impetus for road safety strategies’ conceptualisations and accounts of their Safe System approaches to accord greater respect towards vulnerable road users than they currently tend to do.

Safe System thinking

In 2008, the OECD and the International Transport Forum (ITF) reported that several countries had adopted a Safe System approach for their road safety policies and programs, including Sweden’s *Vision Zero* and the Netherlands’ *Sustainable Safety*. The OECD/ITF added that, while different jurisdictions share similar core principles of Safe System thinking, more specific details of the approaches are suggested by differences between countries. Similarly, Johnston, Muir and Howard (2014) more recently noted that, despite the mutability of Safe System conceptualisations, fundamental aims and principles endure. A central aim common in Safe System approaches is to better manage the forces involved in a crash such that, when an error leads to a crash, no individual road user is exposed to levels of force that exceed the capacity of the human body to withstand those forces (OECD/ITF, 2008; Johnston, Muir & Howard, 2014). Traffic safety agencies need a deep understanding of such critical factors in the road and traffic environment, along with safer road users, safer vehicles and infrastructure, and safe travel speeds, as these factors influence the most prevalent types of crash (OECD/ITF, 2008; Johnston, Muir & Howard, 2014). These aims and understanding are all the more vital when those involved in crashes are road users who by definition are the most vulnerable due to their limited capacity to withstand crash forces.

Vulnerable road users in current Safe System thinking

The NRSS (ATC, 2011) acknowledges pedestrians as having one of the highest rates of death and injury among vulnerable road users as a group, yet pedestrians in relation to a Safe System receive no dedicated coverage in that strategy apart from a short mention that they benefit from lower vehicle speeds and certain infrastructure treatments such as school speed zones and pedestrian crossings.

Similarly, the NRSS provides little more than passing references to cyclists as vulnerable road users. While the document sees the Safe System approach as underpinning the entire strategy, it is essentially applied to motorists rather than vulnerable road users (Shaw, Poulos, Rissel et al., 2012). Moreover, while major cycling documents such as *The Australian National Cycling Strategy 2011-2016* (Austroads, 2010) and Austroads guides relevant to cycling (van den Dool, Murphy & Botross, 2014; Jurewicz, Steinmetz & Phillips et al., 2014) both state that the Safe

Table 2. Summary of reviewed traffic conflict studies

Context of traffic conflict study	Findings relevant to Safe System	Reference
Pedestrian crashes at signalised pedestrian crossings	Shortened pedestrian crossing times increased pedestrian – vehicle conflicts	Greater London Authority (2014) (UK)
Longitudinal data of pedestrian – vehicle crashes	Identification of priority locations for intervention treatments	Kronenburg, Woodward & DuBose et al. (2015) (USA)
Vehicle distance as proxy for random driver error	Weak association of driver error with pedestrian – vehicle crashes, but such crashes had strong association with system errors	Dumbaugh and Li (2011) (USA)
System failures and extreme behaviours as causes of fatal crashes	Majority of crashes ensue from failings of the road system	Wundersitz, Baldock & Raftery (2014) (Australia)
Holistic pedestrian safety evaluation methods	Methods of identifying traffic situations and locations relevant to pedestrian – vehicle conflicts	Tolford, Renne & Fields (2014) (USA)
Drivers, cyclists and motorcyclists' situational awareness along the same traffic route	Drivers, cyclists and motorcyclists exhibited different situational awareness of the same road features, giving potential for traffic conflicts	Salmon, Lenné & Walker, et al. (2013) (Australia)
Cyclist collisions at intersections where cyclist has right of way	Traffic conflict reduced with installation of cycle crossings and deflecting cyclist pathways on intersection approaches	Schepers (2013) (Netherlands)
Cyclist collisions at roundabouts	Increased crashes found at roundabouts explained by increased numbers of cyclist – vehicle conflict situations	Harris, Reynolds & Winters et al. (2013) (Canada)
Cyclist collisions in local area streets	Local streets with painted cycle lanes were safer if infrastructure diverted motorised traffic away from the streets with cycle lanes	Harris, Reynolds & Winters et al. (2013) (Canada)
Cycle track infrastructure	Attractive infrastructure on designated cycle tracks increases patronage, thereby reducing cyclist-vehicle conflicts on busy roads	Nuworsoo, Cooper & Cushing et al. (2012) (USA)
Traffic conflicts involving motorcyclists	Infrastructure treatments identified through discussion of motorcyclist traffic conflicts with highway design specialists and motorcycling groups	Schaffer, Heuer & Bents et al. (2011) (USA) Nicol, Heuer & Chrysler et al. (2012) (Europe)
Vehicle drivers' responses to pedestrian and cyclist behaviours	(study is ongoing)	Chrysler & Hamann (2015) (USA)
Effects of various vehicle technologies on vulnerable road users	Technologies that enhance the detectability and visibility of vulnerable road users have high potential to increase the safety of those users	Scholliers, Bell & Morris et al. (2014) (Europe)

System approach is relevant to cyclist (and pedestrian) infrastructure, these documents tend to focus on the needs of individual cyclists yet offer few detailed suggestions as to how to apply Safe System principles to promote cycling safety in the *broader* context of the transport system.

Compared to its coverage of pedestrian and cyclist safety, the NRSS (ATC, 2011) provides much more detail for motorcyclist safety. This may be because, as the NRSS states, motorcyclist deaths have increased by 17% over the past decade, reflecting in part the increased usage of

motorcycles over this time. However, while the NRSS says it recommends infrastructure treatments in response to these trends, it provides little further detail.

Some recent road safety action plans of individual Australian jurisdictions reflect a growing understanding of a need for increased emphasis on vulnerable road users in light of active travel trends. For example, the New South Wales action plans for cyclists and pedestrians (Transport for New South Wales, 2014a, 2014b) developed in consultation with user groups, call for cycling corridors rather than

isolated facilities, consideration of the needs of cyclists on high speed roads, consistency across pedestrian areas in reduced speed limits, more pedestrian-friendly crossings and encouraging new vehicle technologies that are sensitive to the needs of vulnerable road users.

Some European countries, such as Sweden (Tingvall, Ifver & Krafft et al., 2013), are also recognising a need to accord greater emphasis to vulnerable road users in road safety strategies. Recently, the ETSC noted that some countries had established an urban street user hierarchy, giving the highest usage priority to walking, cycling and public transport modes, based on a “principle of prudence” (Adminaite, Allsop & Jost, 2015, p.19) governing the relationship between drivers and vulnerable road users and new approaches to urban road planning.

Enhancing the status of vulnerable road users in Safe System thinking

Given the growth in walking, cycling and motorcycling and the increased frequency of serious injury among cyclists and motorcyclists, the need for safe relevant infrastructure is paramount. Beyond the NRSS, the Australian Government’s Department of Infrastructure and Transport (DIT) acknowledges that a key barrier to efforts to increase walking and cycling is inappropriate infrastructure in relation to the speed and volume of traffic (DIT, 2013). It calls for:

- separation of pedestrians and cyclists from fast traffic
- ensuring walkways and cycle paths are constructed appropriately for their tasks (including disability access); and
- prioritising pedestrian and cyclist travel in high-pedestrian areas at the same time as reducing traffic volume and speed through these areas.

Implicit in these actions is the need to ensure that the infrastructure called for is ‘forgiving’ of crash forces as a consequence of human error or fallibility. But should such traditional emphasis on a forgiving system be sufficient in Safe System thinking when vulnerable road users are considered? World-renowned road safety expert Professor Fred Wegman has cautioned, “While the Safe System concept has been present in Australia for many years, its implementation still proves a challenge...” (Wegman, 2012, p. 5). In relation to vulnerable road users, this challenge may only partly lie in a Safe System’s traditional call to develop and implement forgiving initiatives that reduce the effects of crash forces when humans make mistakes. Some recent vulnerable road user research is revealing potential value in implementing Safe System approaches that emphasise not just forgiving infrastructure, but endeavouring to minimise, if not eliminate, traffic conflicts and particularly conflicts between vehicles and vulnerable road users.

A broad range of such traffic conflict studies considered in the Austroads review of the NRSS are summarised below in Table 2. Taken collectively, they constitute a

strong foundation for reconsidering the status accorded to vulnerable road users in Safe System thinking.

The first study listed in Table 2 illustrates that simply installing more pedestrian safety infrastructure will not necessarily reduce pedestrian road trauma if there are problems with the way that infrastructure operates, and particularly if pedestrian-vehicle conflicts are not reduced as a result. The Greater London Authority (GLA, 2014) realised this when it investigated why a quarter of its pedestrian crashes occurred at pedestrian crossings. The GLA found that ‘green man’ crossing times had been reduced in the interests of achieving a smooth flow of vehicular traffic. However, this was having the effect of encouraging some pedestrians to take greater risks to ‘beat’ the green light change, and discouraging some older and disabled pedestrians from using particular crossings altogether, and perhaps then attempting to cross at locations without pedestrian crossings. To solve the apparent dilemma, the GLA recommended increasing the installation of cameras that can detect the numbers of pedestrians at a crossing and their speed of crossing, and adjust each signal phase accordingly.

The GLA study provides a microcosmic illustration of the importance of studying potential traffic conflicts in their broader (Safe System) contexts. The City of San Francisco (Kronenberg, Woodward & DuBose et al., 2015) examined longitudinal data of its pedestrian-vehicle crashes to classify the most frequent crash types at sites experiencing the most pedestrian crashes. Teasing out various factors in the road system, as well as relevant human and environmental factors, afforded a data-driven planning process for interventions at priority locations to reduce pedestrian-vehicle conflicts.

Major system-level work in North America by Dumbaugh and Li (2011) suggests that crashes, including those involving pedestrians and cyclists, are the product of systematic patterns of behaviour *associated with the built environment* rather than merely the result of errors by drivers. Using vehicle miles of travel as a proxy for random error by drivers, their regression analyses found a weak association of driver error with crashes involving motorists and pedestrians. However, stronger associations were found between such crashes and system error characteristics of the built environment. Dumbaugh and Li considered that the factors associated with a vehicle crashing into a pedestrian (or into a cyclist) are largely the same as those resulting in a crash with another vehicle. These two researchers rightly pointed out that the correlations they found are not proof of causation and research is needed into how drivers and other road users adapt their behaviours in response to the built environment and how those behaviours may affect their exposure to crash risk. Nonetheless, substantial analytical work in Australia by Wundersitz, Baldock and Raftery (2014) has, similarly to Dumbaugh and Li, concluded that relatively few road crashes are the consequence of extreme behaviour, rather, the vast bulk should be interpreted as failings of the broader road system.

Dumbaugh and Li (2011) believe their results suggested that improvements to urban traffic safety require designers to balance the ‘inherent tension between safety and traffic conflicts, rather than simply designing roadways to be forgiving’ of human error (2011, p. 69). The NRSS (ATC, 2011), under ‘Safer Roads’, does not use the word ‘forgiving’ in relation to infrastructure, merely saying that road and roadside treatments are important for preventing crashes or minimising crash consequences. Nonetheless, this coverage is still one step removed from Dumbaugh and Li’s assertion that the real focus should be on addressing the tension between safety and traffic conflicts brought about by the built environment.

One prime example of such tension is that the spatial distribution of pedestrian crashes shows that they cluster around urban arterial roads, which are typically designed for higher vehicle speeds (Dumbaugh & Li, 2011). This often results in pedestrian (and cyclist) advocates calling for design features that reduce driver speeds and which buffer pedestrians (and cyclists) from oncoming traffic. However, while these approaches serve to reduce the opportunities for conflicts between motorists, pedestrians and cyclists, they do not focus on addressing the *causes* of those conflicts that Dumbaugh and Li contend stem from system error in the built environment rather than from human error.

This need to understand system errors as causes of traffic conflicts appears to be reflected in what has become known as the ‘Complete Streets’ movement in the USA (Schlossberg, Rowell & Amos et al., 2015). The concept of Complete Streets challenges the traditional priority accorded to vehicular mobility and flow along major streets in favour of focussing on multiple travel mode usage, but without necessarily adversely affecting vehicular mobility. In a typical example, a four lane road (two lanes in each direction), with no median strip or bike lanes, is turned into a two lane road (one lane in each direction), with two bike lanes plus a median strip facilitating traffic turns. Despite the two fewer lanes for vehicle travel, vehicular mobility and flow can actually improve, if not remain unaffected, due to the designated bike lanes and the median strip reducing chances of conflict when vehicles make turns. Some studies (such as Tolford, Renne & Fields, 2014) have developed low-cost methods of holistic pedestrian safety evaluation relevant to Complete Streets initiatives. These methods are both cognisable of and adaptable to diverse situations due to their seeking a range of data relevant to traffic conflicts. For example, as well as pedestrian-vehicle crash statistics, the approach also considers pedestrian volumes and ages, diversity of activity in the pedestrian areas, presence of pedestrian generators (such as shopping areas, schools and bus stops), peak hour times, low income neighbourhoods, pedestrian safety priorities identified by residents and vehicle speed limits.

Dumbaugh and Li’s (2011) call for research into how drivers and other road users adapt their behaviours in response to the built environment might have been heeded by a research team who recently studied how a sample of drivers, cyclists and motorcyclists described their experiences in negotiating a 7km route in Melbourne that included intersections,

arterial roads, roundabouts and a shopping strip (Salmon, Lenné & Walker et al., 2013). The research team found the drivers, motorcyclists and cyclists exhibited markedly different situational understandings even when operating in the same road environments. Such differing situational awarenesses can create conflicts between these types of road user, particularly at intersections. For example, at intersections, drivers commonly focus their situation awareness on infrastructure aspects such as traffic lights, the lights’ status and the area in front of their vehicle, whereas motorcyclists’ and cyclists’ situational awareness is strongly oriented towards other traffic and the behaviour of other road users. This could contribute to conflicts when riders manoeuvre themselves around intersections in areas that drivers do not focus on, such as the left and right sides of their vehicle. Likewise, drivers may not become aware of riders until they are just ahead of their vehicle. Overall, the research concluded that situation awareness is heavily related to the road environment in which the road users are operating, and that road and infrastructure design have a critical role in supporting situation awareness across different road users and in enabling different types of road user to relate to each other better.

A major UK review of literature on infrastructure and cycling (Reid & Adams, 2011) somewhat pre-empted Dumbaugh and Li because, while the review noted that cyclist casualties are primarily the consequences of human behaviour, it pointed out that this occurs in a context formed by infrastructure, law, culture and the behaviours of other road users. For example, large roundabouts are effective at maximising motorised vehicle traffic speed and flow through intersections, and in reducing the chances of severe crashes for motorists, however roundabouts remain especially hazardous for cyclists. Some cyclist-specific infrastructure treatments, such as painted cycle lanes and cycle advanced stop lines (or boxes) have shown only limited effectiveness in improving cyclist safety. Moreover, while providing segregated paths for cyclists has had some success in reducing cycling risks, this tends not to be the case where the segregated paths intersect with roads. Indeed, there is evidence that the risk to cyclists at such locations is not offset by the safety benefits of segregating them from motorised road users (Reid & Adams, 2011). Overall, the review (Reid & Adams, 2011) considered that the best approach to improving cyclist safety is to reduce motorised traffic speeds in conjunction with segregated pathways. However, this approach, in Dumbaugh and Li’s view, would still not address the more fundamental issue: the tension between cyclist safety and traffic conflicts where the road environment allows cyclist pathways and motorised traffic to intersect.

Nonetheless, in recent years, much research on improving cyclist safety has centred around traffic conflicts. For example, Dutch research (Schepers, 2013) found that more collisions occur at intersections where the cyclist has right of way, but that the crash probability can be reduced if there are raised bicycle crossings at the intersection and if the cycle path approaches to an intersection are deflected between 2 and 5 metres away from the road. Cyclist crashes from

traffic conflicts at intersections were also studied recently in Canada (Harris, Reynolds & Winters et al., 2013). It was found that intersections of two local streets had much lower risks than intersections between two major streets, but risks to cyclists were increased where roundabouts existed. The study noted that the increased risks could be attributed to the greater number of traffic conflict points attendant on roundabouts, with the two main types of crashes at roundabouts studied being due to collisions with motor vehicles where the cyclist was not seen, and single cycle crashes where the cyclist collided with infrastructure such as the kerb. The study also found that, while cycle tracks alongside major streets but physically separated from motorised traffic reduced collision risk, for local streets cycle tracks were safer when there was infrastructure that tended to divert motorised traffic away from using the streets having cycle tracks. Work in California (Nuworsoo, Cooper & Cushing et al., 2012) reported that other cycle track infrastructure such as cycle parking, route directness of the track, wide lanes for passing each other and traffic light phases for cyclists crossing a road are likely to increase usage of cycle tracks, thereby removing cyclists from regular roads and reducing the incidence of cycle/motor vehicle crashes.

Traffic conflicts involving motorcyclists have been studied in Australia (Allen, Day & Lenné et al., 2013). The most common conflict scenario reported in the 75 crashes studied was another vehicle turning into the path of a rider. Moreover, half of the crashes occurred at intersections and a fifth occurred on a curve or bend, while in 27% of

cases it was calculated the rider was exceeding the speed limit. In the USA, a study by Schaffer, Heuer and Bents et al. (2011) aimed at identifying forgiving infrastructure for motorcyclists rather than aiming for reduced traffic conflicts involving them. However, the research team's approach identified the infrastructure through a consultation process involving discussion of traffic conflicts among highway design specialists and various motorcycle rider groups committed to improving motorcyclist safety. A similar traffic conflict consultation process was employed in a European scan of motorcyclist safety (Nicol, Heuer & Chrysler et al., 2012). Other cooperative European research (van Elslande, Feypell-de La Beaumelle & Holgate et al., 2014) concluded that the Safe System approach should be modified with respect to motorcycling by focussing on strategies that aim to avoid crashes (through reducing potential for conflict) rather than merely mitigating their effects (such as by forgiving infrastructure).

Vehicle technology is a key component of any holistic approach to improving traffic safety. The US National Highway Traffic Safety Administration (NHTSA) (2013) places importance on developing technological capability in vehicles to detect the presence of pedestrians and in avoiding collisions with them. The NHTSA also recognises the potential for traffic conflicts with pedestrians posed by quieter vehicles such as electric cars and hybrid models. In an ongoing project, Iowa University (Chrysler & Hamann, 2015) is also studying how vehicle drivers respond to pedestrian and cyclist behaviours, but from the perspective of developing and improving in-vehicle technologies



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that can warn drivers of a potential traffic conflict with a vulnerable road user. At the specific operational level, Kings County in Seattle (2015) is trialling turn warning technology on its public buses. The warning system is activated when a bus turns a corner, such that English and Spanish recorded voices can warn nearby pedestrians and cyclists with the message: “Caution, bus turning”, accompanied by activation of an external strobe-light.

There is also European-based research into vehicle technology with potential to reduce conflicts with vulnerable road users. An extensive European Commission study (Hynd, McCarthy & Carroll et al., 2015) concluded that among the most worthwhile vehicle technologies for reducing vehicle and vulnerable road user conflicts are: intelligent speed adaptation, assistance to keep a vehicle in lane, and reversing systems that can detect the presence of vulnerable road users, particularly children. One specific project has involved assessing the impacts, usability and efficiency of various vehicle technologies on vulnerable road users in traffic scenarios that are critical for vulnerable road user safety (Scholliers, Bell & Morris et al., 2014). One type of critical scenario occurs when the vulnerable road user is poorly visible to a motorised driver, or is otherwise easily overlooked by the driver. The study concluded that technologies and systems that enhance the detectability and visibility of vulnerable road users are considered to have high potential to increase vulnerable road user safety. For example, blind-spot detection systems in trucks, and devices (possibly using smartphone technology) allowing communication between motorcycles and larger vehicles, show much promise in reducing truck-cyclist and motorcyclist-vehicle conflicts respectively (Admainite, Allsop & Jost, 2015; Scholliers, Bell & Morris et al., 2014). The European Union is urging its member states to change their legislation to permit the re-design of driver cabins in heavy vehicles to afford greater visibility of vulnerable road users (Admainite, Allsop & Jost, 2015). Also advocated by the EU (Scholliers, Bell & Morris et al., 2014) are intelligent pedestrian traffic signals (as in the earlier GLA example (GLA, 2014)).

Discussion

Collectively, the examples above tend to be of studies that do not aim to simply identify the safety benefits or otherwise of various forms of infrastructure and vehicle technologies. Rather, the studies aim for a better understanding of the contextual nature and causes of traffic conflicts involving vulnerable road users in the first place, and then looking at how infrastructure and vehicle technology can serve to minimise or eliminate those conflicts. This is important because vulnerable road users are receiving smaller benefits than vehicle occupants from recent road safety improvements (ITF, 2014), which also suggests that Safe System thinking towards vulnerable road users is not as well developed as it is for vehicle occupants. Just as important, however, is that an emphasis on minimising or eliminating traffic conflicts, obtained through a better understanding of their contextual nature, particularly for vulnerable road users, has much potential to contribute to the Safe System

thinking and conceptualisations that now underpin our whole approach to road safety. The emphasis should urge Safe System models to extend beyond their traditional focus on susceptibility to crash forces and systems that are forgiving, to provide for a greater recognition of the vulnerability of pedestrians, cyclists and motorcyclists in the Safe System model, as highlighted in many recent traffic conflict studies and in best practice principles for urban design.

Moreover, in seeking a better understanding of what should constitute a Safe System for vulnerable road users, it needs to be acknowledged that pedestrians, cyclists and motorcyclists have different experiences of traffic conflict and may well need different requirements in terms of a Safe System.

Conclusions

Collectively, vulnerable road users need a Safe System that extends its core principles currently acknowledging tolerance of human error and susceptibility to crash forces, and hence implementing a forgiving system, to embracing a new core principle, that of recognising the need to eliminate or minimise the potential for traffic conflict. Such an expanded direction in Safe System thinking, while of particular benefit to vulnerable road users, would turn out to be of benefit to all road users.

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Contributed articles

Road Safety Policy & Practice

Automated vehicles supporting “Towards Zero” Initiative

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Key Findings

1. First public demonstration globally by Bosch of an SAE Level 3 automated vehicle.
2. Automation, driver monitoring, HMI, and connectivity concepts presented.
3. Highly automated vehicle prepared in Australia using local and global resources.
4. Bosch Australia are preparing for a future when HAD vehicles are mainstream.
5. Bosch Australia supporting community discussions for a “zero accident” future.

Abstract

Many of us talk about a future where there are zero accidents and all vehicles are automated or driverless. It sounds attractive but how easy is it to automate a vehicle that is suitable for all driving conditions? What are the considerations we must engineer into such a vehicle? This paper explores some of the technology and highlights many of the challenges that are being confronted by Bosch in the drive to achieve a zero accident future.

Keywords

Automated Driving; Bosch; ITS World Congress

Glossary

HAD – Highly Automated Driving
 ITS – Intelligent Transport Systems

SAE – Society of Automotive Engineers
 TAC – Traffic Accident Commission
 ABS – Antilock Braking System
 TCS – Traction Control System
 ESC – Electronic Stability Control