So you want to increase cycling on roads: then we need side underrun barriers on all trucks

Rechnitzer G.[a] and Grzebieta R.H.[a],

[a] Transport and Road Safety (TARS) Research, University of New South Wales (UNSW)

Abstract

With increased promotion of bicycling on roadways throughout Australia, it is well overdue that we introduce the requirement that all trucks have side underrun barriers. Such barriers are necessary to help prevent cyclists (and pedestrians) from falling under the side and rear wheels of these vehicles when passing and turning. Side underrun barriers have been required in Europe for some decades now, and in many parts of Asia. This paper presents the types of systems being used in Europe and Asia and the requirements for an Australian Standard specifying truck side underrun barriers. A recent case of a bicyclist fatality due to falling under a turning truck has once again highlighted the need for such barriers which the Authors have called for some twenty years. While installation of side underrun barriers are being promoted by some heavy vehicle industry groups and regulators, and being fitted, there is an urgent need for comprehensive attachment of these devices to all trucks, particularly if cycling numbers continue to increase.

Introduction

In Australia, heavy vehicle crashes contribute around 15% of road deaths overall and has been fairly consistent over the past decade in the proportion of road fatalities (BITRE, 2014). Most at risk are not the heavy vehicle occupants but the *"other road users"* making up 74% of these fatalities (2014b).

The authors' extensive in-depth crash investigations and review of literature over the past three decades have identified that the lack of compatibility, and aggressiveness of heavy vehicle design is a major causal factor leading to the overrepresentation of heavy vehicles in serious injury and fatal crashes involving vulnerable road users such as cyclists. These findings counter the commonly held notion that the main problem is the mass of the heavy vehicle - a factor that is not readily amenable to change. Importantly, the Authors have identified that design changes to heavy vehicles can be effective in reducing the injury risk to vulnerable road users such as cyclist, pedestrians and motorcyclists.

For example, in Australia in his 1966 study of 59 crashes involving trucks, in the city of Adelaide, Mclean (1966) suggested the fitting of both rear underrun barriers and side skirts to trucks to reduce the injury potential for these crash types.

In Sweden, Hogstrom and Svensson (1986) of Volvo, have studied over 1000 truck involved crashes, since 1970. They concluded that side skirts would have a positive effect in 35% of crashes involving cyclists and motorcyclists.

In their 1976 study of 740 fatal crashes in Britain, Riley et al (1981), of the 300 fatalities involving unprotected road users, two thirds of these involved impact with the side of the

heavy vehicles. Of these, 98 were run over by the rear wheels. Their estimate is that side skirts would have saved 39 two wheelers and 14 pedestrians.

Otte (1987, Germany), in an in-depth at scene crash study of 325 crashes involving heavy vehicles with a mass greater than 3.5 tonnes, noted that for two wheelers 48% involved the front of the truck and some 20% of crashes were with the side of the truck. Otte stated that *"..the side is especially dangerous due to protruding, often edgy structures and the possibility of running or driving under the vehicle"*.

Otte (1987) found that 22% of the injuries to two-wheelers and 27% of pedestrians resulted from being run over by the wheels. They recommended the incorporation of deformable front structures on trucks and the use of side panels to prevent 2-wheelers from riding under the vehicle between the axles. They also noted the need to have the impact points being at the same level as the energy absorbing structures on the cars and that of the two wheelers.

In Germany Langweider and Danner (1987), noted that a significant number of side impacts could be described as "glancing", such as can occur during overtaking manoeuvres. The injury causing mechanism is not the speed but the danger of the subsequent fall into the space between the front and rear axle, resulting in being run over by the truck's wheels. They found that side-underrun protection would influence around 50% of serious and fatal injury cases to drivers of two wheeled vehicles. In particular these guards would totally avoid the falls between the wheels. They recommended that side panels should be designed with flat surfaces covering the whole side area. This contrasts with other designs which employ side rails with gaps between them, which can present their own hazards as people can still be caught between the rails.

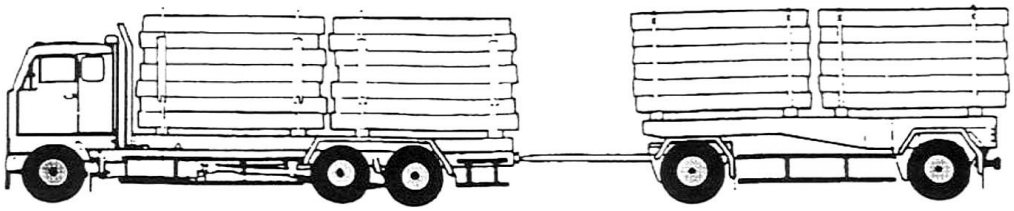
Langweider and Danner (1987) examined 110 incidents involving pedestrians, finding that 42% were with the front of the truck and 33% with the side. They recommended that the design of the front and side should present flat surfaces, without protruding edges, and particularly noted the need for this between the truck's cab and the load platform. They also noted that two-thirds of truck crashes are at speeds less than 30km/h and that the suggested measures of incorporating front underrun protective devices and side skirts, would therefore be effective.

Side Design Of Heavy Vehicles

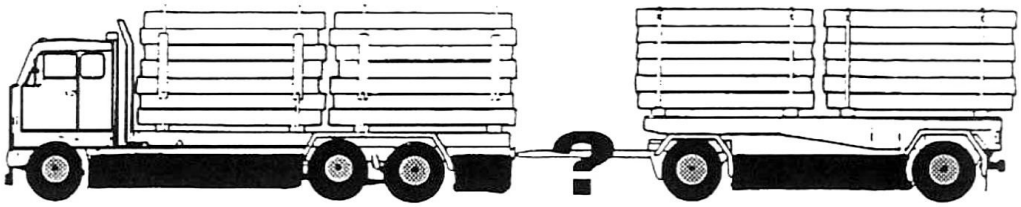
Walz et al (1990) in their review of truck involved crashes in Switzerland, noted that side protection on trucks was first raised as a major issue in 1973, and even as early as 1912. Their recommendation is to fit sideguards to all trucks. These guards should be of the flat panel type, with the use of the rail type not recommended as this leaves the risk of being caught between the rails (Figure 1). They recommend that ECE Regulation No. 73 (Lateral Protection Of Trailers And Semi-Trailer Goods Vehicles, United Nations February 29, 1988) should be adopted by all countries as soon as possible - with retrofitting of existing vehicles made compulsory.

Riley et al (1985) in their work at TRRL set out requirements for effective side guards on HVs. They recommended fitting of side panels to all new vehicles and retrofitting to some existing larger semi-trailers. The sideguard should have a maximum ground clearance of 300mm, and mounted flush with the load platform edge. They noted that the British

requirement allowing 550mm clearance when the semi-trailer is horizontal, is not satisfactory as when the trailer is mounted this clearance would increase.



Early proposal of side rails to protect two-wheelers from underrunning. (Högström 1974)



Flat side guards prevent two-wheelers and pedestrians much more effectively from being thrown under the truck than simple side rails. Moreover, they reduce noise and water spray.

Figure 1: Illustration of side underrun guards, comparing side rails and flat panels. (after Waltz et al., 1990)

Australian Fatality Data and Characteristics of the Side Design of Trucks

In order to assess how many vulnerable road users have been killed where either a rigid truck or articulated truck has been involved, data from the Australian Bureau of Infrastructure, Transport and Regional Economics (BITRE) was accessed and is summarised in Table 1. It

	Pedestrain			Motorcyclists			Cyclists		
	Articulated	Rigid	All Trucks	Articulated	Rigid	All Trucks	Articulated	Rigid	All Trucks
2004	14	15	29	3	8	11	3	6	9
2005	11	11	22	9	10	19	4	3	7
2006	20	12	32	8	10	18	6	1	7
2007	19	12	31	10	8	18	5	7	12
2008	17	15	32	11	11	22	4	3	7
2009	20	10	30	3	9	12	0	3	3
2010	14	7	21	7	9	16	6	5	11
2011	20	14	34	6	6	12	2	4	6
2012	16	12	28	8	12	20	0	4	4
2013	7	17	24	7	5	12	2	6	8
			283			**160**			**74**

Total (10 years): Pedestrain+Motorcyclsit+Cyclist = 517

Table 1: Truck involved fatalities of vulnerable road users (BITRE, 2014b)

shows that over the past ten years there have been 74 cyclist fatalities, 160 motorcyclist fatalities and 283 pedestrian fatalities, i.e. a total of 517 people killed over the past ten years that could have benefited from some form of better design of truck under-run barriers and side guards. Moreover, the data shows that the number of deaths have remained fairly constant of the past decade. One could propose that the designs of heavy vehicles have changed over the past decade and this data is reflecting that road safety crashworthiness deficiency.

The particular focus of this paper is the smaller subset of ongoing crashes involving side underrun for vulnerable road users, which on current trajectories, are likely to increase due to increased cycling promotion and projections of major increases in heavy vehicle traffic. The basic proposition put in this paper is that side underrun barriers have been used worldwide for decades to help reduce the risk to unprotected road users, and such measures should be also implemented in Australia. Under a Safe System paradigm, there is no excuse for ignorance or inaction on developing with industry a program of implementing effective side underrun barriers on all new heavy vehicles, to prevent such predictable, recurring deaths.

Side Underrun by Cyclists

Rechnitzer (1993) investigated 45 truck related fatalities of which three fatalities involved the death of cyclists which found themselves trapped between the front of the vehicle and its rear wheels. The major risk associated with the side of commercial vehicles relates to underrun and the subsequent danger of being run over by the rear wheels of the truck. Most commercial vehicles have large open areas between the cab and rear wheels, and because of the height of the tray (850 to 1100mm typically) there is no intervening structure to prevent pedestrians, cyclists or motorcyclists from falling under the tray and being crushed by the rear wheels.

The case on the left shown in Figure 2 highlights this mechanism and the ease with which it can occur. In this case the cyclist was traveling beside a slowly moving rigid truck, with the cyclist apparently falling from his bike (may have slipped on the wet road) and rolling under the rear wheels. The rear wheels ran over the cyclist's chest, resulting in fatal chest injuries. Had this truck been fitted with side skirts, the cyclist would most likely have been deflected away from the side of the truck, receiving relatively minor injuries as a consequence of the fall only.

The second case in Figure 2 (red truck) is another example of a bicycle fatality involving the unprotected side of a rigid truck. In this case the 9 year-old cyclist (apparently not wearing a helmet) impacted the mudguard, just forward of the rear wheel, and did not actually underrun the truck. It would appear that the head and chest injuries arose due to impact with the steel framing of the van. It is doubtful that side skirts would have made much difference in this particular case. The main issue highlighted is how to prevent head impact with the steel framing. In this regard side skirts should be at least flush with this framing and preferably cover the framing with a panel with some deformation capability ("padding").

The lack of side skirts on trucks poses a double hazard for motorcyclists. They can fall under the truck as described and be crushed by the rear wheels, or they are exposed to severe head and chest injuries by underunning the rigid tray of the truck. In addition, motorcyclists (and cars) are also vulnerable to underrun whilst traveling beside a heavy truck, when either the vehicle turns or during lane-changing manoeuvres.

ECE Regulation No. 73 For The Provision Of Lateral Protection On Goods Vehicles, Trailers And Semitrailers.

The ECE 1988 regulation is given in Appendix 3 of Report No. 35 by Rechnitzer, (1993b). The regulations are applicable to vehicles and trailers greater than 3.5 tonne gross mass. The regulation's objective is to offer effective protection to unprotected road users (pedestrians, cyclists, motorcyclists) against the risk of falling under the sides of the vehicle and being caught under the wheels. The major technical requirements of R73 are (also see Lambert et al, 2002):

- the side guard can consist of a flat panel, or of one or more side rails.
- if side rails are used the maximum spacing is 300mm, the minimum rail width is 50mm for category N2 & O3, the minimum rail width is 100mm for category N3 & O4

Figure 2: Two bicycle underruns cases investigated by Rechnitzer (2003).

- the lower edge of the sideguard shall be a maximum of 550mm above the ground 109
- the sideguards shall be essentially rigid, and able to withstand a horizontal static force of 1kN, applied at any point on the guard.

The regulation also sets out detailed dimensional requirements at the sides and ends of the sideguards. The British Standard (refer Appendix 4 in Report No. 35, Rechnitzer, 1993b) sets out detailed requirements for the guard dimensions, similar to the ECE requirements. A major difference noted is the specification of a 2kN test load compared with the ECE test load of 1kN.

The clearance under the barrier of 550 mm as recommended by ECE R73 is much too high to ensure unprotected road users are not run over by the wheels of the heavy vehicle. Preferably side underrun guards should not be rails as there is the potential for unprotected road users to be caught up in them. Some Australian trailer manufacturers are moving to incorporate side underrun protection as shown in Figure 3. Note however that with no Australian standard such barriers may be less than optimal.

Recommendations On Side Guards

Currently all buses have lightweight sideguards, designed and built as part of their normal design. It presents an example that currently exists in Australia of how trucks could be designed to provide better side underrun protection. It is evident from inspection of these structures that they are able to sustain significant impacts from vehicles, let alone unprotected road users. The ECE and British regulations have very low test load requirements (1 to 2kN), and the Authors are not aware of any references which have commented on the strength of the guards.

Based on the cited research and testing, and the detailed crash investigations undertaken (Rechnitzer, 1993, 1991, 1991b), improvements to the ECE regulations would require:

- lowering the ground clearance to around 350mm. This may have to be increased for some vehicles to take into account special clearance requirements;
- flat panel surfaces only, with railings not permitted (Figure 3 and 4);

Figure 3: Top: Underrun side skirting made from rails by an Australian manufacturer which are not suitable. Bottom: Underrun side skirting made from bins being more appropriate in terms of being mor representative of a smooth panel surface.

Figure 4: Examples of different side underrun guards on trucks in Europe, comparing flat panels sides (left) with the use of rails (right) (after V. Middelhauve, Germany)

- all exposed edges to be radiused (say 20-50mm) to reduce edge loads on unprotected road users;
- adoption of the British load test of 2kN. As this is quite a small load, review whether a higher load is justified for effective performance.

Other issues relating to the side design of heavy vehicles is the streamlining of the side shape, making it free of projections and reducing any underrun potential. The best example of this new style of vehicle is shown in Figure 5 which is the Mercedes Benz EXT advanced prototype. This vehicle incorporates many of the design modifications required to reduce the vehicle's harm potential. It has low front underrun barriers, it is fully skirted with smooth flat surfaces, with no projections behind the driver's cab.

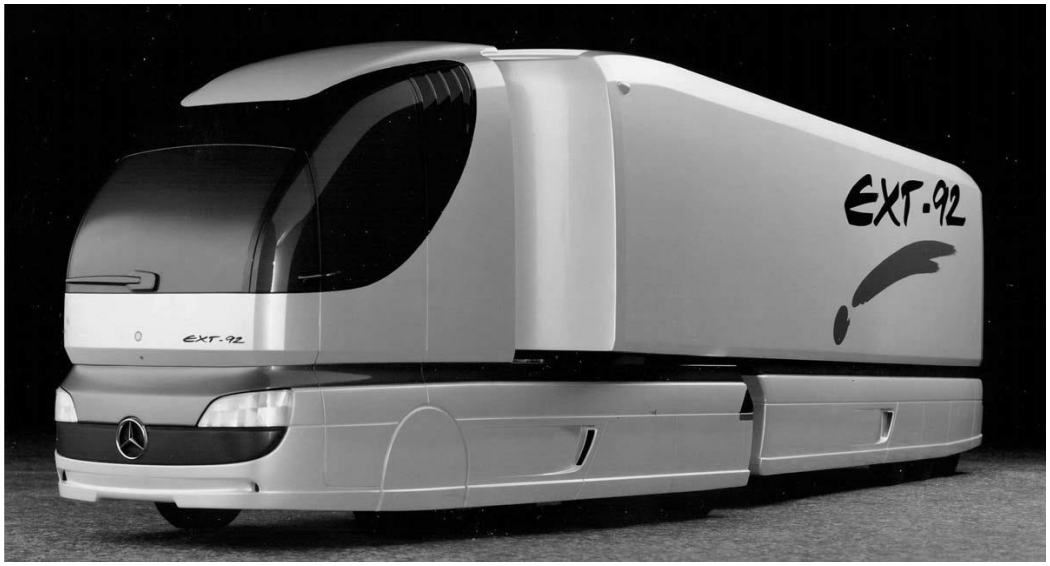


Figure 5: European Experimental Truck EXT-92 shown at the commercial vehicle show Hanover, May 1992. This articulated heavy vehicle illustrates many advanced features including a design which minimises the harm potential to other road users: front and rear underrun protection, smooth side skirts, no projections or sharp edges, spray suppression etc. (Photo courtesy Mercedes Benz Australia)

Similarly Figure 6 highlights the smooth surfaces and lack of protruding edges around the body of a Ford truck. Also shown is a well-designed model BP petrol tanker in Australia, with flat panel side skirts.

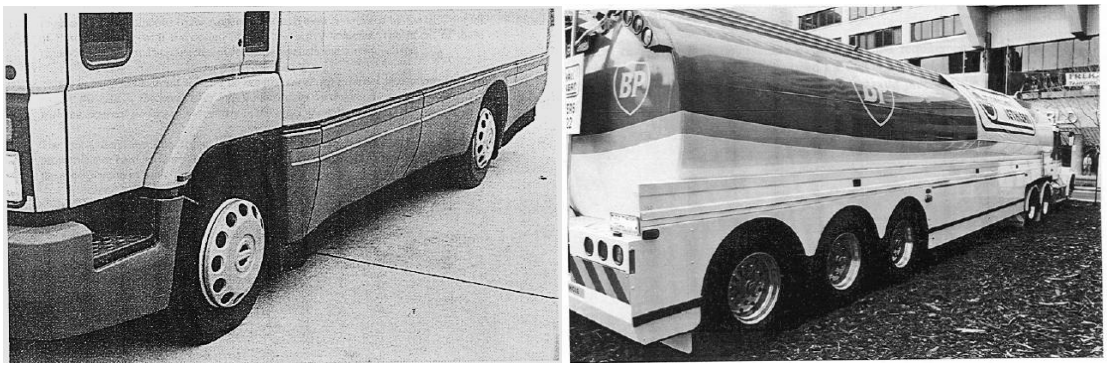


Figure 6: The left picture shows detail of the side skirting of a Ford Truck in Europe illustrating smooth side structure free of protruding edges (V. Middelhauve Berlin Technical University). The right photo is of a BP petrol tanker with side skirts in Melbourne Australia.

In Australia, the 2009 'Regulation Impact Statement for Underrun Protection' (DOTARS, 2009) identified approximately 43 fatal and serious injuries side underrun cases involving all road users per annum, and that these 'are expected to increase in the future, given an expected doubling of the freight transport task by 2020'. On a cost- benefit analysis basis, the RIS recommended against mandating side underrun protection for rigid trucks and articulated vehicles.

Of course such non regulation means an ongoing and likely increased toll of fatal and serious injuries for all road users due to lack of effective action on requiring side underrun protection on all heavy vehicles.

More recently the Australian Trucking Association's (ATA) Industry Technical Council (2012), has developed an "Advisory Procedure - Side Under Run Protection". It states that "*This Technical Advisory Procedure (TAP) has been developed by the ATA-ITC (and endorsed by the Australian Trucking Association General Council) to provide trailer builders and operators with general construction guidelines for a lateral protection device that would be deemed to comply with the requirements of UN-ECE R73. These devices aid the safety of vulnerable road users such as pedestrians and cyclists by removing many opportunities for accidental access into the wheel space of trucks and trailers, and can also provide aerodynamic benefits*."

Conclusions and discussion

The number of road users killed in side underrun heavy vehicle involved collisions appears to have remained fairly constant over the past decade at around 43 deaths and serious injuries per year. While side underrun cases involving unprotected road users are a smaller subset of these fatalities, nevertheless under a Safe System paradigm, there is no excuse for ignorance or inaction on developing with industry a program of implementing effective side underrun barriers on all new heavy vehicles, to prevent such predictable, recurring deaths.

We estimate an approximately 30% effectiveness in the reduction of fatality and serious injuries of all road users by fitment of well designed side underrun protection on all new heavy vehicles (over 3.5t). We estimate over 3 to 4 cyclist fatalities per annum Australia wide, and likely more in future, will be saved from being killed due to side 'underrun' crashes with heavy vehicles. Such barriers will also provide improved protection for pedestrians and motorcyclist in such potential collision scenarios.

The general aspect of heavy vehicle design which appears to contribute to the fatalities and serious injuries in crashes involving vulnerable road users such as cyclists and the sided of trucks was found to be geometric incompatibility of the truck structure and the cyclist. Effectively the design allows underrun by cyclists.

The necessary principle for injury prevention in *any type* of such impact is dependent on the application of a *principle of interface compatibility*. In reality what can be seen in many areas of road safety, as exemplified by the study of this particular collision mechanism involving heavy vehicles and vulnerable road users, is the general lack of knowledge and application of this principle.

This paper has identified that the side design of trucks *can* be significantly improved to reduce the harm potential in crashes involving cyclists (as well as other vulnerable road users such as pedestrians and motorcyclists). This is in line with European findings, which countered commonly held notions maintaining that the main problem was the mass of the truck- a factor that was not readily amenable to change.

This idea of *interface compatibility* is part of a broader view of safety, as set out by Tingvall et al (1999), Rechnitzer & Grzebieta (1999), Grzebieta & Rechnitzer (2001), Rechnitzer et al (2009) on the need for *crashworthy systems*. The inspiration leading to developing the concept of

'crashworthy systems' arose from the Vision Zero philosophy originated by Tingvall (1998) which also formed the basis of the Safe System Approach (Mooren et al, 2014).

While installation of side underrun barriers are being promoted by some heavy vehicle industry groups and regulators (see ATA, 2012), and being fitted, there is an urgent need for comprehensive attachment of these devices to all trucks, particularly if cycling continues to be heavily promoted and numbers continue to increase.

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