A Cost-Benefit Analysis of Heavy Vehicle Underrun Protection

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Biography

Mark Symmons is a Research Fellow at Monash University Accident Research Centre, where he has been involved in research on a number of road safety areas, including heavy vehicles, motorcycles, and rural roads. Other areas of interest include environmental aspects of road use and rail safety.

Abstract

Victoria's road crash database does not directly identify truck underrun crashes. A total of 3,488 potential underrun crashes were selected on the basis of DCA codes for the period 1996-2000 inclusive. The three most common types of crashes involved rigid trucks – a rigid truck hitting the rear of a lighter vehicle, followed by a lighter vehicle striking the side of a rigid truck, and then a rigid truck running into the side of a lighter vehicle. The fourth, fifth and sixth most common types of crashes involved articulated trucks: an articulated truck hitting the rear of a light vehicle, followed by an articulated truck running into the side of a lighter vehicle, and then a lighter vehicle striking the side of an articulated truck. Fatalities were most likely to occur in crashes involving the front of a truck.

A number of assumptions underpinned the calculation of benefit:cost ratios (BCRs), including the actual occurrence of underruns and the effectiveness of underrun protection. For all of the underrun protection scenarios examined, the BCRs were higher for articulated than rigid trucks. The package of front, side and rear underrun had a BCR of greater than 1 for both articulated trucks and rigid trucks, regardless of whether the cost was $500 or $1,000 and whether a 15- or 25- year lifetime is assumed. The BCR also exceeded 1 for each type of underrun protection – front (at a cost of either $100 or $200), side or rear – for both articulated trucks and rigid trucks; again regardless of the lifetime.

1. INTRODUCTION

Crashes between trucks and smaller vehicles generally produce a more severe outcome for the occupants of the smaller vehicle due to the large mass discrepancy. Additionally, modern cars are designed to dissipate energy through crumple zones, but trucks will absorb very little of the crash energy. There is also incompatibility in terms of ride heights. The front, sides and rear of a rigid or articulated truck with a trailer are often at the same height (or higher) than the bonnet or boot of a car. Thus, when a smaller vehicle and a truck collide, significant intrusion and injury to car occupants can result.

Truck underrun protection devices can be fitted to the front, rear or side of a truck/trailer, and are designed to engage car safety systems during a crash and reduce the degree of intrusion into a car's passenger compartment. Some devices also crumple to absorb impact energy. According to Lambert and Rechnitzer (2002), all underrun protection devices should have road clearances no greater than 350mm. Rear and front devices should be full width across the truck, have a 300mm buffer between them and the truck's chassis, and be constructed from a progressive crush material.

Many trucks are fitted with an underrun barrier of some description, although there is a lack of consistency in their construction (ADR 42/03 only deals with rear underrun protection (Lambert and Rechnitzer (2002)), and few trucks would be completely equipped on all sides to prevent an underrun occurring. In order to determine the efficacy of requiring all trucks to be fitted with adequate underrun protection, the likely effectiveness in terms of safety benefits needs to be determined, and these benefits balanced against the costs of installation.

This paper examines Victoria's crash data to estimate the prevalence of crashes where underrun protection has the potential to reduce injury severity. The frequency of underrun crashes Australia wide is extrapolated from the Victorian data and cost-benefit ratios for fitting all trucks with underrun protection are then estimated. A more detailed description of the research can be found in Haworth and Symmons (2003).

2. DATA ANALYSIS

2.1 Determining the number of underrun crashes

Truck-involved crashes that occurred during the period 1996-2000 inclusive were extracted from the Victorian State Traffic Accident Record database. Underrun crashes can not be directly identified in the database, however crash types that could potentially involve an underrun were selected on the basis of the Definitions for Classifying Accidents (DCA) coding system. Twenty-eight of the 81 possible DCA codes describe potential underrun scenarios, but whether a particular crash involved an underrun is unknown. For example, a car may collide with the side of a semi trailer, but hit the wheels of the trailer without any underrun occurring. Additionally, the DCA code assigned to a multi-vehicle crash only describes the interaction of two primary vehicles. Accordingly, a vehicle that underruns a truck that has already collided with another vehicle will not be identifiable in the database.

A total of 3,488 crashes that could have involved an underrun of any configuration were identified – 2,445 front underruns, 986 side underruns and 432 rear underruns (the addition of these three numbers exceeds the total number of actual crashes due to double counting, which is accounted for in Table 1). Table 1 summarises the numbers of each crash severity type, categorised by truck type and underrun type.

A truck colliding with the back of another vehicle while both vehicles were travelling in the same direction (DCA code 130) was the most common type of front underrun crash (contributing 630 crashes, or 60% of the category total). The most common head-on crash (346 crashes, or 98%) occurred where one of the vehicles was travelling on the wrong side of the road and neither vehicle was overtaking (DCA 120). The most common side-on crash involving the front of a truck was where the vehicles approached each other at right angles at a cross intersection (DCA 110) – 309 crashes (33%). Of the crashes where a truck has collided with the side or rear of another vehicle, 64% (70 crashes) involved a truck hitting another vehicle as that vehicle was making a U-turn (DCA 140).
Fourteen DCA codes describe crashes where another vehicle has hit the side of a truck. The most common of these 986 crashes is DCA 110 (a cross-intersection crash) with 309 crashes, or 31% of the total side underruns. These 309 crashes were also included in the total for front underruns, as the database does not adequately identify whether the front of the truck impacted the side of the smaller vehicle (a front underrun) or the front of the smaller vehicle hit the side of the truck (a side underrun). The actual configuration of the particular crash depends on which vehicle entered the intersection first, and the crash database does not reliably allow this distinction to be made. Ten DCA codes describe crashes where another vehicle has collided with the rear of a truck. Of these 432 crashes, 218 (51%) occurred when the other vehicle was travelling in the same lane behind the truck (DCA 130).

Three DCA crash configurations are common to side and rear underrun scenarios – DCAs 140 (u-turns), 142 (another vehicle hits the truck as it enters traffic from a parked position) and 152 (another vehicle hits the truck as it pulls out of or across a lane). Whether a particular crash is a side or rear underrun depends on the stage during the manoeuvre when the crash occurred, and this can not be determined from the crash database.

Table 1. Number of potential underrun crashes (Victoria 1996-2000). (Adjusted for double counting.)

Underrun	Type of crash	Crash severity Fatal	Serious injury	Other injury	Total crashes
ARTICULATED TRUCKS					
Front	*Truck into rear of light vehicle*	*4*	*65*	*308*	*377*
	Truck into front of light vehicle	*42*	*41*	*58*	*141*
	Truck into side	*21.5*	*96*	*231*	*348.5*
	Truck into side or rear of light vehicle	*6*	*24*	*18*	*48*
	Total front underrun	73.5	226	615	*914.5*
Side	Light vehicle into side of truck	16.5	86	170.5	273
Rear	Light vehicle into rear of truck	3	50	82.5	135.5
	Articulated trucks total	**93**	**362**	**868**	**1,323**
RIGID TRUCKS					
Front	*Truck into rear of light vehicle*	*5*	*118*	*545*	*668*
	Truck into front of light vehicle	*30*	*90*	*93*	*213*
	Truck into side	*24.5*	*126*	*282.5*	*433*
	Truck into side or rear of light vehicle	*4*	*17*	*41*	*62*
	Total front underrun	63.5	351	961.5	1376
Side	Light vehicle into side of truck	19.5	149	357	525.5
Rear	Light vehicle into rear of truck	7	83	180.5	270.5
	Rigid trucks total	**90**	**583**	**1,499**	**2,172**
ALL TRUCKS					
Front	*Truck into rear of light vehicle*	*9*	*183*	*853*	*1045*
	Truck into front of light vehicle	*72*	*131*	*151*	*354*
	Truck into side	*46*	*223*	*513.5*	*782.5*
	Truck into side or rear of light vehicle	*10*	*41*	*59*	*110*
	Total front underrun	137	578	1576.5	2291.5
Side	Light vehicle into side of truck	36	236	525.5	797.5
Rear	Light vehicle into rear of truck	10	126	263	399
	All trucks total	**183**	**940**	**2,365**	**3,488**

More fatal crashes involved frontal impacts between light vehicles and trucks (rigid or articulated) than the combined total of crashes where a light vehicle collides with the rear or side of a truck. The same pattern is true for serious injury and other injury crashes. In terms of individual types of crashes, the most common underrun crash types were:

- Fatal crashes: for both artic and rigid – truck into the front of a lighter vehicle
- Serious injury crashes: artic – truck into side of lighter vehicle; rigid – light vehicle into side of truck
- Other injury crashes: artic – truck into rear of lighter vehicle; rigid - truck into side of lighter vehicle.

2.2 Cost-benefit analysis of underrun protection Australia-wide

In 1992, 1994 and 1996, 20% of Australia's 468 fatal articulated truck crashes and 17% of 326 fatal rigid truck crashes occurred in Victoria (from ATSB Fatality file). Similar information is not available for truck crashes resulting in serious injury or other injury. Assuming that the distribution of serious injury or other injury crashes is similar to that of fatal crashes, and that the distribution of underrun crashes follows that of all truck crashes, then the number of underrun crashes Australia-wide can be estimated by extrapolating from the Victorian data (see Table 2).

Table 2. Estimated annual number of potential underrun crashes Australia-wide as a function of injury severity.

Type of protection	Crash severity		
	Fatal	Serious injury	Other injury
ARTICULATED TRUCKS			
Front underrun	73.5	226.0	615.0
Side underrun	16.5	86.0	170.5
Rear underrun	3.0	50.0	82.5
RIGID TRUCKS			
Front underrun	74.7	412.9	1131.2
Side underrun	22.9	175.3	420.0
Rear underrun	8.2	97.6	212.4
ALL TRUCKS			
Front underrun	148.2	638.9	1746.2
Side underrun	39.4	261.3	590.5
Rear underrun	11.2	147.6	294.9

An average heavy vehicle crash has been estimated to cost 50% more than other crashes at the same severity level (BTE, 2000; Cairney, 1991), and so these costs can be estimated as:

- Fatal crash $2,479,491
- Serious injury crash $611,985
- Other injury crash $20,664

These values were applied to the crash distribution displayed in Table 2, with the assumption that only half of the potential underrun crashes actually involved an underrun. The resulting estimated annual total cost of underrun crashes in Australia is approximately $594 million. Front underrun crashes account for almost two-thirds of this amount. Using the same cost for articulated and rigid truck crashes may not be appropriate, given that the cost of the cargo and the truck itself is likely to be higher for a damaged articulated truck. However, in many underrun crashes there is little damage to the truck and cargo.

From a review of the literature, Rechnitzer (1993) estimated the likely effectiveness of underrun protection devices in terms of the reductions in fatalities and injury severity resulting from improved frontal and side design of trucks. These reductions are summarised in Table 3.

Table 3. Estimated reductions in fatalities and injury severity resulting from improved frontal and side design of trucks (from Rechnitzer, 1993).

Crash type	Expected reduction in fatalities	Estimated reduction in injury severity for injury cases
Car-truck	15+%	30%
Pedestrian-truck	20%	25+%
Two wheeler-truck	20+%	25+%
Total	16%	28%

Underrun protection will not prevent crashes. In most instances, it will save lives and reduce the extent of injury, but some level of injury is still likely to occur. Reductions in the cost of property damage are expected to be small compared to the benefits in terms of savings in lives and long-term injuries. The analysis presented here assumed that:

- Front underrun protection will change 15% of fatal crashes to serious injury crashes and 30% of serious injury crashes to other injury crashes
- Side underrun protection will change 15% of fatal crashes to serious injury crashes and 30% of serious injury crashes to other injury crashes

- Rear underrun protection will change 30% of fatal crashes to serious injury crashes and 30% of serious injury crashes to other crashes

Effective rigid rear underrun systems do not require significantly more material or work than is currently used. The cost varies from about $200 to $500. Energy-absorbing rear underrun systems would work at speeds up to 70-90 km/h for airbag-equipped cars and would cost roughly $1,000 to $1,500. Costs could be somewhat less with good commercial design development. Front underrun systems as used in Europe comprise a simple steel beam at a cost of about $100 to $150. One European manufacturer stated that they did not regard the front underrun protection to be any additional cost as it was used to support other components.

BCRs were estimated for the following scenarios:

- A package of front, side and rear underrun costing $500 and $1,000
- Front underrun protection costing $100 and $200
- Side underrun protection costing $200
- Rear underrun protection costing $200

The number of trucks to which these costs should be applied was taken from the numbers of articulated and rigid trucks in the Survey of Motor Vehicle Use (ABS, 2001), which estimated that during the 12 months ending 31 October 2000 there were 341,484 rigid trucks and 59,989 articulated trucks in Australia. Some of these trucks will already have adequate underrun protection fitted, but it was assumed that this would reduce both benefits and costs in a similar manner, and therefore the benefit:cost ratios would not be affected. The calculations assumed a 7% discount rate with lifetimes of 15 years or 25 years (see Haworth and Symmons (2003) for details of the BCR calculations).

The package of front, side and rear underrun had a BCR of greater than 1 for both articulated trucks and rigid trucks, regardless of whether the cost was $500 or $1,000 and whether a 15- or 25- year lifetime is assumed (see Table 4). The BCR also exceeded 1 for each type of underrun protection – front (at a cost of either $100 or $200), side or rear – for both articulated trucks and rigid trucks; again regardless of the lifetime. For all of the underrun protection scenarios included, the BCRs were higher for articulated trucks than rigid trucks.

Table 4. Summary of benefit:cost ratios for a range of underrun protection measures for articulated trucks, rigid trucks and all trucks.

Measure	15 year lifetime			25 year lifetime		
	Artic	Rigid	All	Artic	Rigid	All
Package ($500)	16.5	4.9	6.6	13.3	4.0	5.4
Package ($1,000)	8.2	2.5	3.3	6.6	2.0	2.7
Front underrun ($100)	54.9	15.0	21.0	44.2	12.1	16.9
Front underrun ($200)	27.5	7.5	10.5	22.1	6.1	5.1
Side underrun	9.0	3.0	3.9	7.2	2.4	3.1
Rear underrun	4.8	1.8	2.2	3.8	1.4	1.8

3. CONCLUSIONS

Crashes involving an underrun are likely to be severe because a car's structural strength and passive safety systems – such as crumple zones – are unlikely to confer their full safety benefit. Many trucks/trailers are fitted with some form of underrun protection, however few trucks are equipped to fully minimise the possibility of an underrun.

As a passive safety device, underrun protection will not reduce the number of crashes involving trucks and lighter vehicles. However, they can ensure that crashes that do occur are less severe than they might otherwise have been. The economic benefit of this reduction in crash severity substantially exceeds the cost of fitting them to trucks, up to a cost of $1,000 for a package of underrun protection for the front, sides and rear of all trucks (the benefit also exceeds the costs for individual underrun devices). This benefit is accrued over a device lifetime of at least 15 years, and is higher for articulated trucks than for rigid trucks. Further work is needed to develop a minimum standard for underrun protection devices for each side of a truck/trailer combination.

References

ABS (2001). Survey of Motor Vehicle Use - 12 Months Ended 31 October 2000 (9208.0). Canberra: Australian Bureau of Statistics.

BTE (2000). *Road crash costs in Australia.* (Report 102). Canberra, Australia: Bureau of Transport Economics.

Cairney, P. (1991). *The cost of truck accidents in Australia: Australian Truck Safety Study Task 4*. (Report ARR 204). Melbourne, Australia: Australian Road Research Board.

Haworth, N. & Symmons, M. (2003). *Review of truck safety: Stage 2 Update of crash statistics.* Draft report. Melbourne: Monash University Accident Research Centre.

Lambert, J., & Rechnitzer, G. (2002). *Review of truck safety: Stage 1 Frontal, side and rear underrun protection*. (Report 194). Melbourne: Monash University Accident Research Centre.

Rechnitzer, G. (1993). *Truck involved crash study. Fatal and injury crashes of cars and other road users with the front and sides of heavy vehicles* (Report 35). Melbourne: Monash University Accident Research Centre.

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Keywords

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