Improving the Design of Heavy Vehicles to Reduce the Injury Risk to Other Road Users in Crashes

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Abstract:

This paper describes the findings from a major study, undertaken for VICROADS examining crashes involving heavy vehicles and other road users. The objectives were to establish the causal factors contributing to the high level of fatalities and serious injuries arising from these crashes and to identify possible countermeasures. In Australia truck-involved crashes contribute 18% of road deaths overall. Of these, 80% are "other road users". The study has included a detailed literature review and detailed investigations of over 52 crashes involving 45 fatalities. The study has identified that the front, side and rear design of trucks can be significantly improved to reduce their harm potential in crashes involving other road users. Detailed recommendations for design improvements are given.

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1. INTRODUCTION

This paper presents findings from a major study (Rechnitzer 1991, 1993) commissioned by VICROADS to investigate *truck design* and its effect on the outcome of crashes involving other road users.

Studies in the USA, Europe and Australia have clearly identified crashes involving trucks and other road users, as contributing significantly to road injuries and death. In Europe truck involved crashes (Goudswaard et al, 1991) make up an estimated 25% (13,000 fatalities per annum) of all road deaths. International studies have also indicated that this toll can be significantly reduced by improvements to the front, side and rear design of trucks (Gloyns and Rattenbury, 1989; Hogstrom and Svensson, 1986; Langwieder and Danner, 1987; Robinson and Riley, 1991)

In Australia some 18% of fatal crashes result from crashes of trucks For rigid trucks 87% of the fatalities (Ogden and Tan, 1987) were other road users, while for articulated trucks the equivalent figure is 78% Cairney (1991), calculated that total cost of truck involved crashes is conservatively estimated at $500 million per annum Camkin (1990) in a paper looking at the regulators viewpoint regarding heavy vehicle (HV) safety, stated that: *" we would like to see an industry in which competition promotes economic efficiency without the substantial community subsidy to the industry to cover its unfunded safety deficit of some $23,000 per annum for an articulated vehicle "*

Though much gain has been made in improving the crashworthiness of cars, and with even higher levels of occupant protection expected, in Australia little progress has been evident in the design of the truck itself to reduce the potential for harm in crashes involving other road users. The 1987 OECD report on the Role of Heavy Freight Vehicles in Traffic Accidents, (OECD, Montreal, 1987) noted that the *design* of current heavy freight vehicles *makes few concessions* with regard to the reduction of crash forces on the occupants of light vehicles.

Mackay (1984), in his study of 226 truck involved crashes, includes a review of the general requirements of car occupant protection: which he states as "...being a strong rigid cell surrounding the occupants, combined with front and rear, and to a lesser extent side zones which are energy absorbing...". These zones provide ridedown and hence reduced acceleration Inside, the cell uses the occupant protection devices of seatbelt and padded instrument panel to reduce the likelihood and severity of occupant injury Mackay concludes that ". To be effective this concept of car occupant protection depends on a measure of compatibility between the car and the object (HV) which is impacted. With current HV design this compatibility does not exist".

The terms *vehicle aggressiveness* and *vehicle compatibility* are significant and are often used in regard to crashes involving trucks and other road users. ***Vehicle aggressiveness*** is defined (MacLaughlin, 1980) as the "characteristics of a particular vehicle which determines the degree to which injury is inflicted upon the occupants of the other vehicle"; and ***vehicle compatibility*** as "the degree to which protection is achieved for all road users"

Australia currently has few regulations or standards dealing with the three major areas of concern on truck design: frontal aggressiveness, side underrun, and rear underrun. The one regulation which is in place is ADR 42 6 which relates to rear underrun barriers. This regulation is restricted to semi-trailers, and is considered to be quite inadequate as a standard for underrun protection (Rechnitzer, 1991). The Australian situation contrasts with various European countries which have had regulations in place for side and rear barriers for some time. In addition proposed European regulations and specification for frontal underrun barriers have recently been announced. Japan also has regulatory requirements for side skirts on goods vehicles

2. OBJECTIVES

The project objectives were to:

- Establish the most influential factors contributing to the high level of fatalities and serious injuries arising from crashes involving heavy vehicles and other road users.
- Identify possible modifications to the structure and design of heavy vehicles (and cars) which would reduce the major injury causing aspects of these crashes
- Compare those safety related regulations regarding heavy vehicle design in force overseas but not currently adopted in Australia

This study was not intended to address the issue of injury to the drivers and occupants of trucks which should be the focus of a separate study.

3. METHOD

This was based on a three phased strategy, which makes appropriate use of past research, available statistical (mass) data and detailed in-depth studies:

- Literature review and comparison of Australian and international design standards and regulations
- Detailed investigation of actual crashes involving trucks (including trams and buses) and other road users. Investigations included documentation of vehicle damage, measurements of deformation, intrusions, and correlation of occupant injuries with the vehicle and truck structure contact points. Particular note was also taken of the structure and configuration of the heavy vehicle at the points of contact in the crash. The crash site was also visited in a number of cases
- Countermeasure development involving identification of design changes to trucks to help reduce their injury potential in collisions.

4. INVOLVEMENT OF TRUCKS IN FATAL CRASHES

Distribution of road user killed or injured

Data from the Australian Federal Office of Road Safety 1988 Fatality File (total of 2561 fatal crashes with 2875 fatalities) provides a distribution of fatalities for crashes involving trucks (a total of 540 fatalities, or 18% of the total) as shown in Table 1.

	Car	Light Commercial	Bicycle	Motorcycle	Peds	Other vehicle	Total
Rigid	83	25	9	20	38	28	203
Artic.	181	39	9	16	24	68	337
Total	264	64	18	36	62	96	540

Table 1. Distribution of fatalities for crashes involving trucks and other road users (FORS 1988 Fatality File, Australia)

Of these truck involved fatalities, 80% are "other road users", representing an annual toll of 400 people killed and 1700 seriously injured. In these multi-vehicle crashes, most at risk are the other road user, not the truck occupants. In Victoria, about 30% of car occupants who are killed or seriously injured in multi-vehicle collisions, are involved in collisions with trucks.

Involvement rates for articulated vehicles (Vulcan, 1987), in particular, are much greater than for other vehicles types. For fatal crashes the involvement rate on a kilometres travelled basis is over 4.3 times greater for an articulated vehicle than for a rigid truck (7.4 vs 1.7 fatalities per 100M kms) and over 3.5 times greater for an articulated vehicle than for a car (7.4 vs 2.1). Comparing involvement rate per registered vehicle shows that an articulated vehicle is more than 14 times more likely to be in a fatal crash than a car (48.5 vs 3.3 fatlities per 10,000 vehicles). For serious injuries, the involvement rate for articulated vehicles is some 4 times that of cars.

An analysis of the risk of being killed in truck involved crashes (Lee, 1987), based on a comparison of the ratio of fatal crashes to total crashes, shows that crashes involving articulated vehicles are over seven times more likely to result in a fatality than car only crashes (6.1% vs 0.8%). Similarly for rigid trucks this ratio is 2.3 times that for car only crashes(1.9% vs 0.8%)

The estimated crash involvement of different parts of the truck are:

For crashes involving other vehicles

- front of the truck: 66%+of fatal; 68% of serious injury crashes
- rear of the truck: 9% of fatal; 17% of serious injury crashes
- side of the truck: 13% of fatal 10% of serious injury crashes.

For crashes involving unprotected road users:

- front of the truck: 42% of fatal crashes
- side of the truck 40%
- rear of the truck 12%

In relating countermeasure requirements in Australia to European experience, it is important to note Europe's higher involvement of pedestrians and other unprotected road users.

For fatal crashes involving HVs:

- Australia has more car -truck involvement (72% vs 50% involve cars)
- Australia has less pedestrian involvement (13% vs 21% involve peds.)
- Australia has less two-wheeler involvement (15% vs 28% involve 2-wheelers)

5. CRASH INVESTIGATIONS: OBSERVATIONS ON THE FRONT, SIDE AND REAR DESIGN OF HEAVY VEHICLES

Characteristics of the Frontal design of trucks

Virtually all of the articulated vehicles had substantial bullbars mounted on the front of the truck. The main function of the bull bar appears to be to protect the radiator of the truck and to a lesser extent the cab and lights from damage in crashes with lighter vehicles or any cattle or kangaroos that may get onto the roads

Although bull bars provide some degree of protection to heavy vehicles, and some of their characteristics are advantageous, overall their interaction with other roads users could only be regarded as hazardous.

In frontal and side impacts with cars, the bullbar structure has low energy absorption and is essentially rigid. Typical car structures with their thin wall thickness, offer little resistance to the direct loading from these rigid and commonly "sharp" edged bullbar sections. In offset impacts high levels of intrusion result with the car's upper structure intruding into the driver's space, often together with direct and catastrophic head contact with the bullbar. An example is shown in Figure 2, an offset glancing type collision, where the driver' head contacted the bull bar directly with gross and fatal injuries

In collisions with the side of cars, the bull bar projects forward and directly into the head space of the vehicle occupants, enabling direct head impact with the rigid, sharp edged structures. In addition the side structure of the car becomes heavily deformed, often resulting in failure of the B pillar at the base, with the front structure of the truck over-riding the doorsill, and intruding significantly into the occupant's space (Figure 3).

The rigidity and height of the bullbar is also significant as it is well positioned to result in "*supported intrusion*" (Figure 1a). In these cases, elements of the truck structure react on the car structure (A, B, C pillars, roof header beams, door structures) and either intrude into the compartment or support the structure as it is impacted by the occupant The occupant strikes a far more rigid and unyielding structure than would have been the case had the truck structure not been there In a major review of the causes of head injuries in real world crashes, Thomas, Bradford and Ward (1991), note that " *head injuries are found to become more severe when the striking object supports the intruding structure.* " and that intruding structures are found to be commonly associated with the most severe injuries as are contacts outside the vehicle

For unprotected road users, bullbars also present an inherently hostile interface: they present an impact surface consisting of "sharp" edges and narrow and unyielding contact surfaces Desirable interface characteristics are those which provide distributed loading to reduce contact stresses and deformable surfaces to reduce accelerations and forces. The elements of a bullbars combine to form the *opposite* (Chiam & Tomas, 1980) of what would be regarded as a desirable interface. The view that injury severity will not be much different whether a bullbar is present or not, ignores the findings from numerous researchers indicating that vehicle design can be successfully modified to reduce harm to unprotected road users. Kajer, Yang and Mohan (1992), in a study of safer bus fronts for pedestrian impact protection, found that it was feasible to improve their characteristics by adding a 160mm thick padding material to the front face of the bus. Accelerations and contact forces were reduced to about 1/3 of the unpadded value

The front structure of rigid trucks shows a greater variation than that observed for articulated vehicles Fewer rigid trucks have bull bars, and where they do they are of lighter construction Bumper bars are typically constructed from steel channel section bolted to the front chassis rails, with ground clearances ranging from 500mm to over 750mm In addition the bumper sections have a relatively low bending resistance, allowing the bumper to be largely ineffective as regards load distribution One consequence is that the bumper simply deforms around the stiff chassis beams which then protrude as two "rams" applying concentrated loads on the car structure. Other bumper designs are also seen to be ineffective. For example, the kevlar (or fibre glass) bumper is seen to fracture and have a relatively low bending resistance

Commonly the bumper will bend allowing underrun of the truck's front. In these cases (refer Figure 4), the initial impact force is taken by the front wheels which are often sheared from the supporting suspension The car continues on colliding with the leading rigid edge of the load tray which projects out beyond the side of the cab, underrunning this This results in high levels of intrusion into the passenger compartment and direct impact with the driver. The characteristics are quite similar to rear underrun crashes.

Characteristics of the Frontal design of Trams and Buses

Examination of the design of the tram's front structure showed that it had a heavy front bumper, attached to the substantial steel framing. The height of the bumper was 550mm. Below the bumper the front of the tram was open, leading to the front of the wheels. Around the front of the wheels is a frame which is intended to push any pedestrians away from the wheels should they fall under the front of the tram It is evident that the front structure of trams provides no energy absorption in crashes with lighter vehicles (or unprotected road users), which are further disadvantaged by the height of the tram's bumper. The front structure is also very poorly designed for pedestrians as the open front structure should be shielded so that pedestrians are deflected away and cannot be trapped under the tram's front. In Victoria with the increasing mixing of pedestrian and tram traffic (for example Swanston Walk, Bourke St. Mall), it is evident that the front of trams needs to be modified to better protect pedestrians, as well as to improve interactions with cars.

As with other types of heavy vehicle, the front structures of buses are not very compatible with other road users as the front structure is quite rigid for impacts with lighter vehicles. The front bumper is a narrow steel channel section attached to the substantial chassis structure (a space truss). This type of structure is "friendly" neither to pedestrians nor lighter vehicles.

Characteristics of the Side design of trucks

For unprotected road users, the major risk associated with the side of commercial vehicles relates to underrun and the subsequent danger of being runover 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. In addition, motorcyclists (and cars) are also vulnerable to underrun whilst travelling beside a HV, when either vehicle turns or during lane-changing manoeuvres

Spearing can occur where framing or trim on the sides of vehicles can be separated from the truck and penetrate the car longitudinally. In each of the cited cases the members finish with a free end such that they could be caught up in a oblique frontal impact The injury consequences can be horrific: in case I2 (Figure 5) the trim from the truck went right through the driver's chest; in case I14 the trim, being more flexible wrapped around the driver, cutting her face; in case F14 the angle framing at the bottom of the side skirt of the van speared the driver through the thigh and groin area- the steel angle was corroded and coated in horse manure.

Examination of the sides of trucks from the perspective of potential impacts by unprotected road users (ie a safety audit approach) reveals numerous areas of potential hazard which would seriously exacerbate the injury outcome. These include the rigid steel framing and other attachments for load tie-down, hooks, door handles proud of the surface and a host of unguarded attachments and fitments. The alternative is to have recessed fittings, streamlined smooth sides avoiding any sharp edges, and the use of side skirts to deflect people away from the truck

In the side underrun cases investigated for the study, the damage to the car consisted of frontal crush with intrusion of the A pillar In this type of underrun crash the body of the van and its stiff floor structure intrudes directly into the occupant space, with the occupant being exposed to direct loading and impact with these structures The provision of side guards on commercial vehicles as recommended for the protection of pedestrians, cyclists etc, would provide some benefit for side impacts involving cars.

Characteristics of the Rear design of trucks

The injury and fatal crashes could be divided into two distinct crash types, depending on the design of the rear of the truck.

Type 1: Where the rear wheels of the truck are set close to the rear (say within 500-mm) the trucks structure acts as a impact barrier, with no excessive underrun. In these cases the current truck structures provide virtually no energy absorption, and the resultant *occupant injuries become a function of the car's crashworthiness* For example in case F17, the drivers fatal injuries (ruptured aorta, with fractured ribs and no head injuries) were a reflection of the significant chest impact with the steering wheel hub combined with the excess movement permitted by the seat-belt. In this case an improved occupant restraint system (eg. belt pretensioner combined with supplementary airbag), may well have prevented the driver's fatal injuries.

Type 2: This is the classic underrun case where the vehicle underruns the rigid tray (or floor of a van) of the truck with consequent high levels of intrusion into the passenger compartment exposing the occupants to fatal or serious head injuries. The impact is generally concentrated on the roof structure and A-pillars, which provide little resistance to this type of direct loading. In these cases the vehicle impact speed can be relatively low (30-40km/h) and still result in serious injury. In excessive underrun crashes, by their very nature, *occupant restraint systems can provide little or no protection to the car occupants.*

For fatal underrun cases, occupant injuries were consistent with a heavy frontal loading to the front (or side) of the face/ head, resulting in depression of the facial structure, with associated severe skull fractures and gross brain injury These injuries are also consistent with the expected result of an underrun crash where the head is exposed to direct impact with the rigid steel framing of the end of the truck or trailer, or in combination with impact with the intruded sections of the roof structure as it is crushed back by the end of the truck (refer Figure 6).

Unsurvivable impacts

For both frontal and side impacts involving HVs, there are a range of crashes which are or appear to be unsurvivable, irrespective of any practical design changes to either vehicles. In these extreme cases one looks to countermeasures which address crash prevention or lower impact speeds. Factors such as HV conspicuity and better braking performance also become pertinent.

6. SUMMARY OF FINDINGS

The general aspects of heavy vehicle design (Figure 1b) which contribute to the high level of fatalities and serious injuries in crashes involving other road users were found to be:

1. High ratio of mass of truck to car combined with the high stiffness of the truck structure results *in little energy absorption by the truck structure*. This leads to a high energy absorption requirement of the car structure, which is further disadvantaged by the mismatch in chassis levels. Consequently the vehicle occupants will commonly experience significantly higher velocity changes compared to "equivalent" car-to-car impacts

2. *Size incompatibility of truck structures with those of other road users* This allows underrun by cars and other light vehicles and consequent significant car occupant compartment intrusion, whether impact is to the front, side or rear of the truck.

3. *Potential for direct occupant contact with unyielding parts* (eg bullbar, or steel framing) of the truck and intruded parts of the car, leading to severe head or chest injuries This problem also applies to pedestrians, cyclists and motorcyclists involved in crashes with trucks.

4. *Unguarded wheel areas of the truck* which allow pedestrians and cyclists to fall under wheels and suffer crushing injuries

5. *Trim on trucks (particularly vans) which can be dislodged* in crashes and spear car occupants.

Other specific findings regarding heavy vehicle design are:

- **HV front bumper performance in collisions:**
    - The heavy bullbars on most articulated trucks are sufficiently low to prevent underrun in lower severity impacts. The main bumper is generally too high for this to be effective in preventing underrun in higher speed impacts.
    - These bullbars help protect the truck's steering system and front wheels from the impact, thus helping the driver to retain vehicle control.
    - In offset frontal and side impacts, bullbars are a major hazard to the occupants of the car as they intrude directly into their head space and can result in direct head impact
    - Bullbar structures are not energy absorbing.
    - Bullbars are a major hazard in impacts involving unprotected road users: they are the antithesis of designs aimed at minimising the risk of injury

- Bumpers on rigid trucks typically allow underrun as they are mounted too high and have low strength. They afford no protection to the steering system or front wheels which can be torn away by the impacting car

- **Height of the truck tray or cab floor:** The stiff floor structure of most trucks is sufficiently high to cause serious or fatal injury to the occupants of cars in an underrun situation.

- **Underrun can be a low speed hazard:** In contrast to other crash types, underrun is a significant hazard even at relatively low speeds As impact occurs generally above bonnet height, the windscreen pillars are incapable of resisting this type of loading and high occupant compartment intrusion can result.

- **Occupant protection systems may become ineffective in underruns:** Underrun *negates* the effectiveness of vehicle occupant protective measures such as seat-belts and airbags, and is more likely to result in direct occupant impact with the truck structure, with consequent severe or fatal head and chest injuries (*supported intrusion*)

- **Current ineffective rear barrier designs could be readily upgraded.** The current ADR regulations *(ADR 42.6 Rear Bumper For Semi-Trailer),* only applies to a very limited range of vehicles, and is known to be inadequate. Observations from the case studies and of vehicles on the roadway, show that many trucks and semi-trailers already have fitted some sort of rear barrier type structure. The configuration of these "guards" varies greatly and it is apparent by observation and the crash investigations that few would act as effective underrun barriers. Common deficiencies are inadequate bracing and connection design and execution, and incorrect height It is also apparent that even in many barriers which are made from substantial structural sections (as seen on semi-trailers, for example), the potential load resistance is *wasted* by inadequate design and detailing

  It is evident that many of these barriers could be redesigned and substantially upgraded in capacity, with little penalty in the way of cost or weight increase, above what is already being incurred.

- Increasing the visibility of trucks ***is only one*** of the necessary countermeasures to reduce the incidence of under-run fatalities and serious injuries (six of the nine trucks involved in the rear under-run crashes investigated, had rear marker plates).

- **The occupant protection performance of cars** must also be upgraded as it is the *interaction* between the two vehicles that leads to the resultant injury severity. Modifications made to the structure of the truck alone can be limited in their effectiveness. Conversely, current improvements to car design including design for offset frontal crashes, dynamic side impact tests, and the introduction of airbags, will be of limited benefit in crashes with heavy vehicles, unless heavy vehicle design is also upgraded

7. CONCLUSION AND RECOMMENDATIONS

The study has identified that the current frontal, side, and rear design of trucks plays a significant role in increasing the injury potential in crashes with other road users, and that these designs *can* be significantly improved to reduce this harm potential. These findings counter the commonly held notions maintaining that the main problem was the mass of the truck- a factor which was not readily amenable to change Importantly, this and other studies have highlighted that design changes are feasible and effective. Indeed it has been noted that the mass aggressiveness is aggravated by the shape, height and stiffness of the HV.

To date, the parameters for the design and configuration of heavy vehicles appear to have been largely dominated by a functional perspective: the direct cost and efficiency of freight handling. The safety of other road users and consequent indirect costs have been given low priority, with little incentive or focus being placed on the benefits attainable and the need to modify the design of trucks to reduce their harm potential to other road users. This general outlook by the freight industry to date is not surprising considering its highly competitive nature.

This situation is changing, however. For example, both the BP and Shell companies have added side skirts to a number of their new petrol tankers; and recently various companies, such as TNT, are upgrading their designs for rear underrun barriers on various new vehicles to new performance standards developed from this project. Recent work carried out by MUARC, VICROADS and the Monash University Civil Engineering Department (Rechnitzer, Scott & Murray, 1993) has demonstrated that a lightweight and inexpensive barrier (Figure 7) can be fitted to the rear of trucks preventing most underruns and with the potential for reducing the severity of others.

The countermeasures relating to reducing the harm potential inherent in current truck design can be categorised into three separate areas:

- Frontal design of heavy vehicles: incorporation of energy absorbing front underrun structures.
- Side design of trucks: the use of side skirts.
- Rear design of trucks: installation of effective rear underrun barriers.

Recommendations.

The following design changes would reduce heavy vehicle aggressiveness and improve compatibility with other road users, and would lead to estimated annual savings of 75 lives and a 28% reduction in injury severity for crashes involving HVs and other road users.

(1) Trucks (and trams and buses) be fitted with energy absorbing front underrun barriers having the following characteristics:

- A road clearance of not more than 350mm; an energy absorbing capacity of 100kJ and a stroke of 500 to 600mm

- A frontal projection of at least 300mm to provide a buffer space in impacts with the sides of cars, and hence reduce the opportunity for direct head and body contact

- Residual strength after full energy absorption, as set out below:

Truck mass GVM	**Force at P1, P3** (outer edge of barrier, centre)	**Force at P2** (off centre)
3.5t to 12t	100 (kN)	1.6xGVM (125 min.)
> 12t	100 (kN)	200

(2) Rigid trucks and semi-trailers be fitted with side guards, having the following characteristics:

- Ground clearance of around 350mm.

- Flat panel surfaces only forming a "continuous surface", with railings not permitted.

- Framing for the side guard to be so constructed and detailed to preclude the possibility of spearing of car occupants in offset impacts, or spearing of unprotected road users. Generally this will require curved returns at the start and end of the guard.

(3) Rigid trucks and semi-trailers be fitted with rear underrun protective devices having the following characteristics:

- ADR 42.6 for rear under-run barrier design for semi-trailers to be revised in line with the European ECE standards (except as noted below)

- Barrier height to be 500mm maximum.

- Satisfy the following test loads:

Truck mass GVM	**Force at P1, P3** (outer edge of barrier, centre)	**Force at P2** (off centre)
3.5t to 12t	100 (kN)	100
> 12t	100 (kN)	150

(4) The front structures of trams and buses incorporate special energy absorbing pads to reduce injury potential for pedestrians and other unprotected road users.

(5) The design of truck cabs and bodies be improved to reduce their harm potential in crashes with other road users by eliminating sharp edges, projections, and trim which can spear other road users.

(6) The conspicuity requirements for the side and rear of trucks be improved to help prevent crashes. Extend the regulation (ADR 13 6.101 Rear Marking Plates) for rear conspicuity to include heavy vehicles and trailers having a GVM less than 12t (and greater than 3.5t.)

(7) Heavy vehicle length regulations be modified to allow specific energy absorbing (add on) bumpers etc to extend beyond maximum length requirements.

(8) The incorporation of override brackets on the front chassis of cars to ensure better compatibility and engagement of energy absorbing structures of both the car and truck, be investigated.

8. ACKNOWLEDGMENTS AND DISCLAIMER

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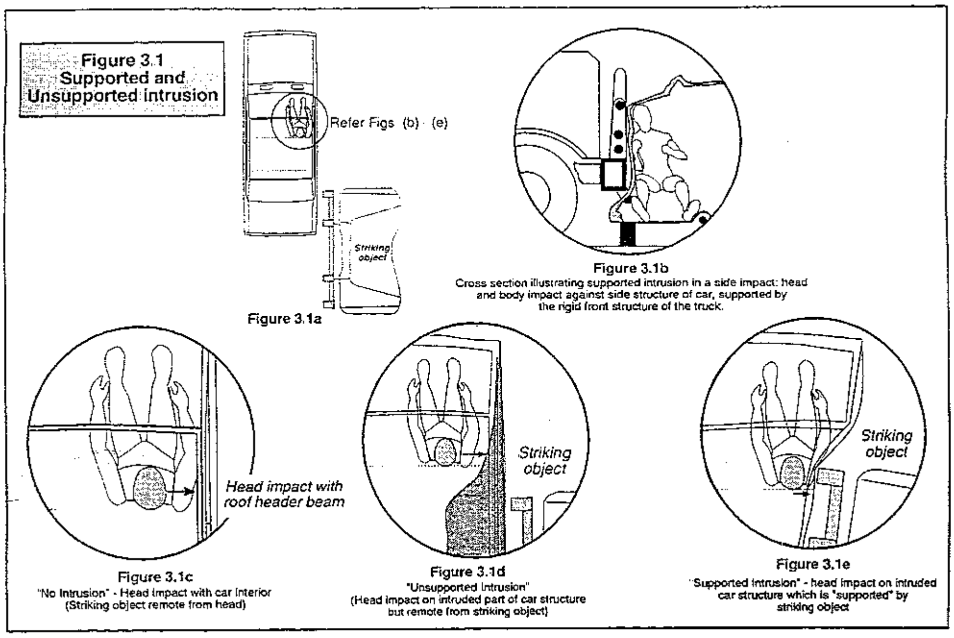


FIGURE 1a
Illustration of supported' and 'unsupported' intrusion in impacts.
(after Figure 3 1. Rechnitzer. 1993)

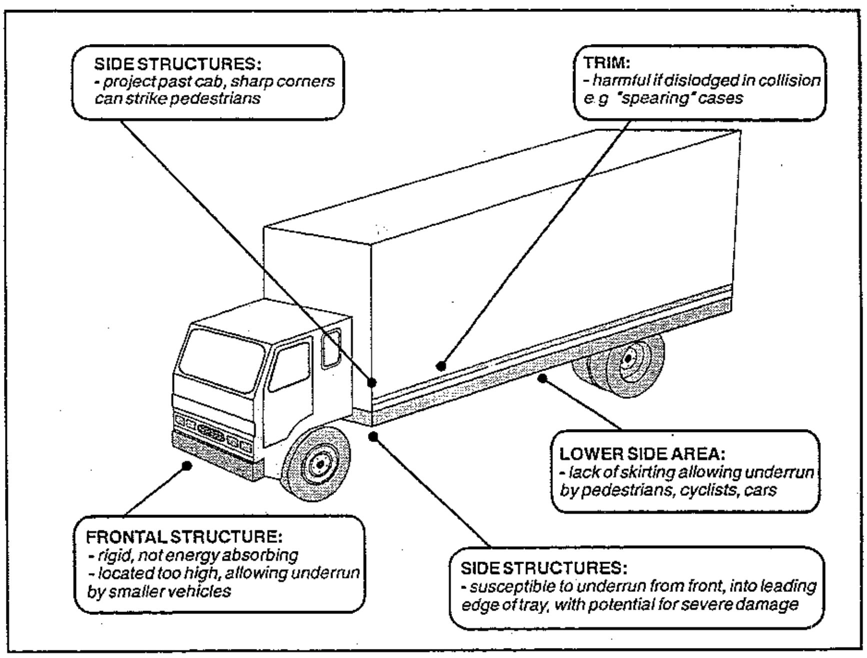


FIGURE 1b *View of rigid truck showing characteristics of frontal and side structures which increase their potential for harm to other road users*
(after Figure 4 2. Rechnitzer. 1993)

Photo F8-1 Front view of prime mover showing damaged bullbar

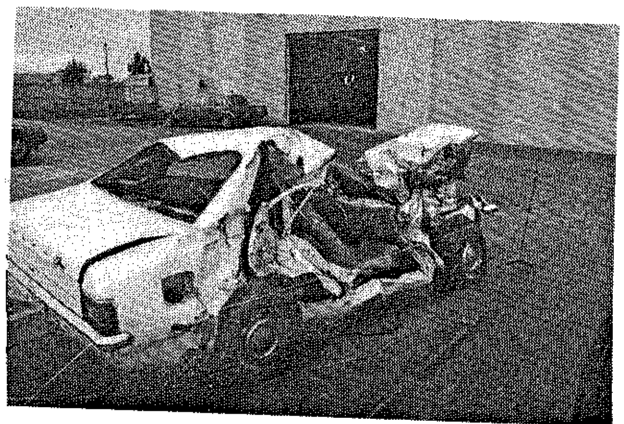
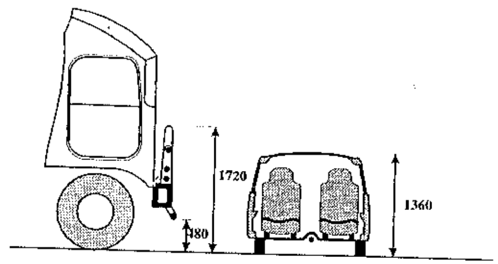
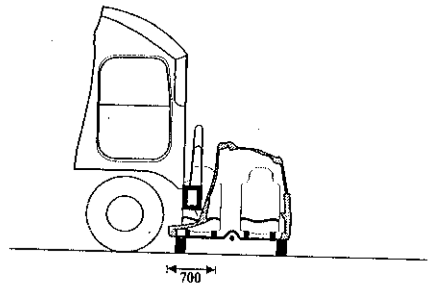


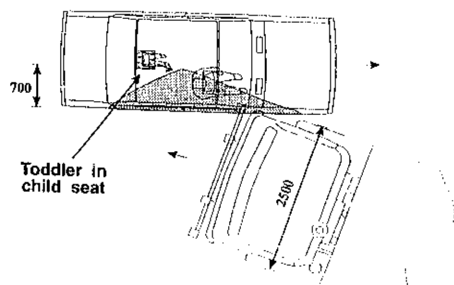
Photo F8-2 View of car showing heavy intrusion to driver's side.



(a)
Cross section through car and side elevation of truck showing relative dimensions of each



(b)
Cross section through car showing intrusion by the bullbar



(c)
Plan view showing relative positions of truck and car

FIGURE 2
CRASH INVESTIGATIONS CASE F8B
(Driver and child killed) Example of offset frontal- sideswipe impact.

CASE F1
(Side impact)

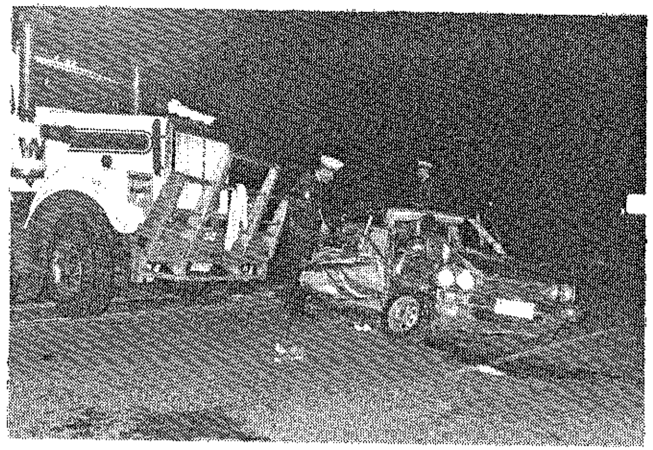


PHOTO 1: At crash scene. Note that bullbar is leaning further forward than usual as the support bracket was bent in crash.

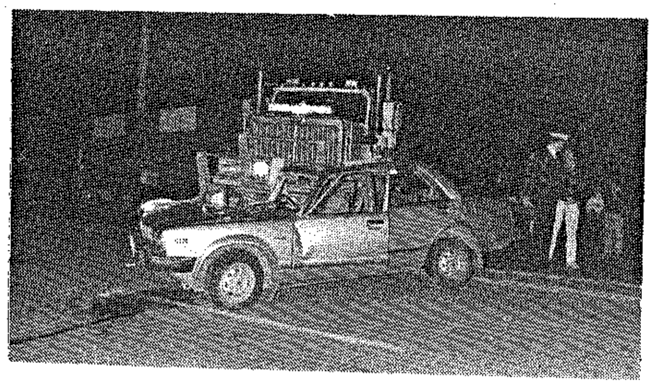
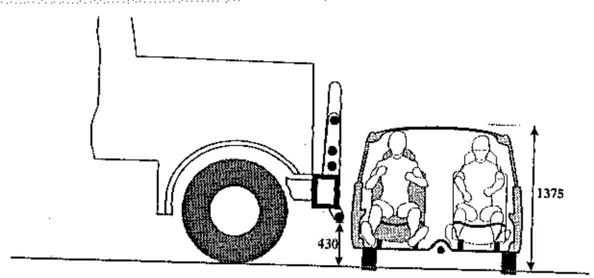
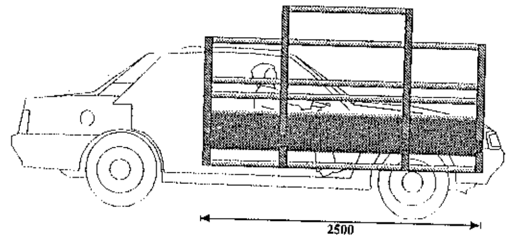


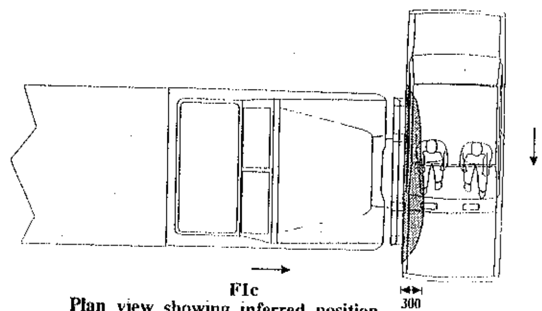
PHOTO 2: At crash scene. (Both photos courtesy Shepparton News)



F1a
Cross-section through car and truck showing position of bullbar structure relative to the side of the car and driver's seating position



F1b
Side view showing the position of bullbar relative to the car and driver



F1c
Plan view showing inferred position of car and truck at impact

FIGURE 3
CRASH INVESTIGATIONS CASE F1
(Driver killed, front passenger seriously injured)
Example of impact of heavy vehicle (with bullbar) with the side of car.

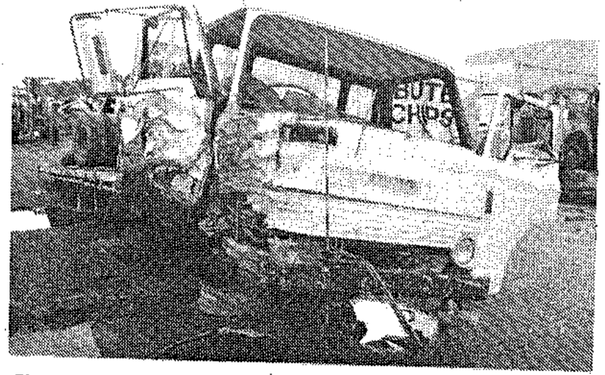
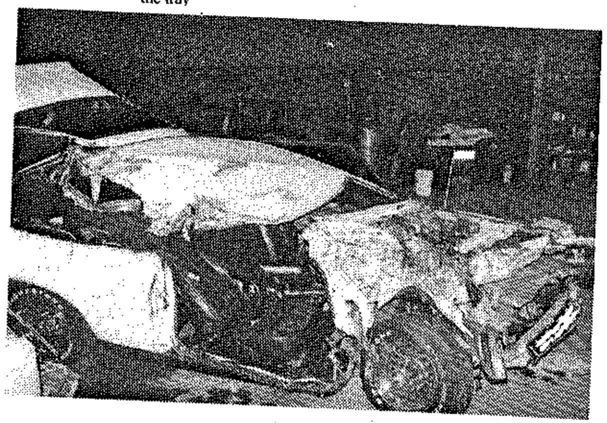
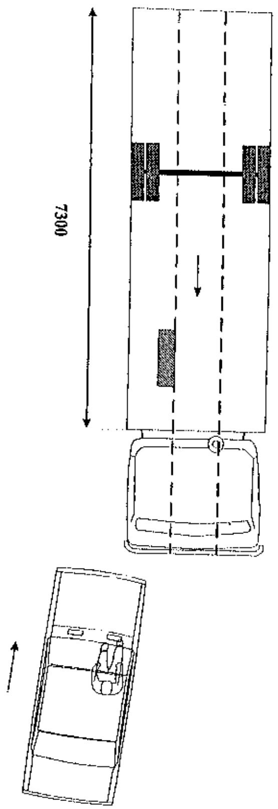


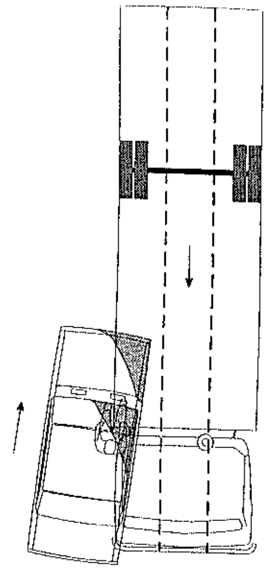
Photo F15-1 View of rigid truck showing offset impact damage: both front and rear axles were torn away by the impact of the car.

Photo F8-2 View of car, note roof damage from frontal underrun to the corner of the tray



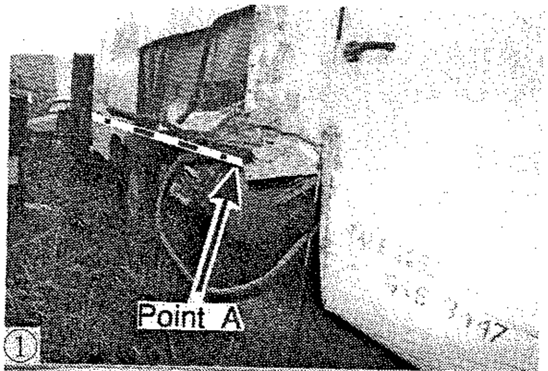


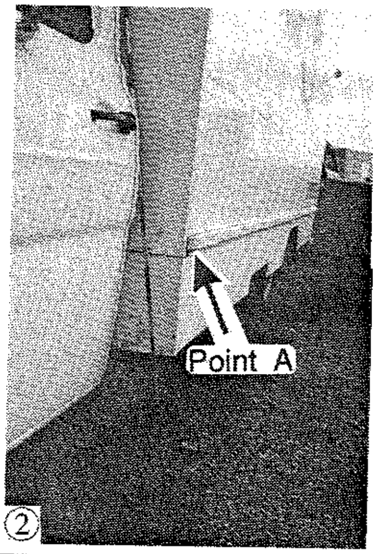
Plan showing offset frontal collision with truck.

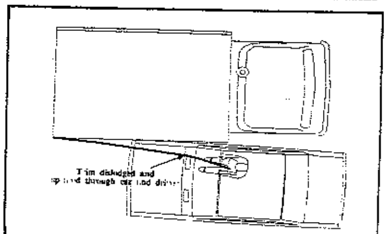


Plan view after impact. Note car under-run to corner of tray

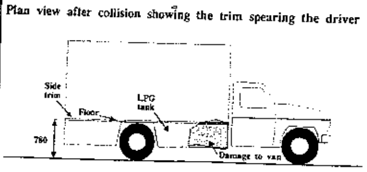
FIGURE 4
CRASH INVESTIGATIONS CASE F15 (driver killed)
Example of offset frontal impact with rigid truck, showing underrun to front corner of tray.



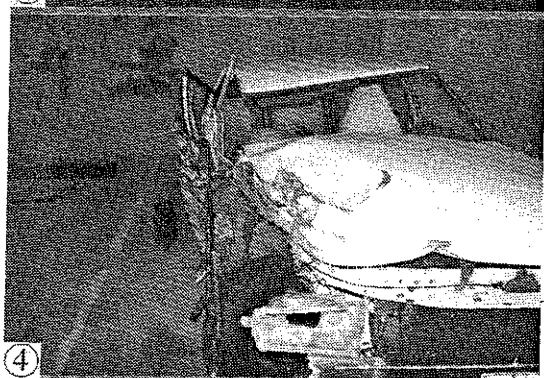




Plan view after collision showing the trim spearing the driver



Side view showing extent of damage to van



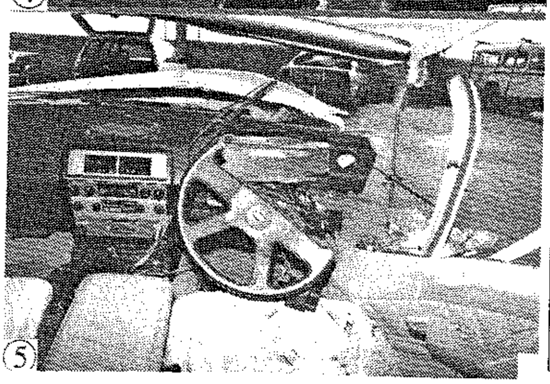


FIGURE 5
CRASH INVESTIGATIONS CASE 12 (driver seriously injured)
Example of frontal impact with spearing

PHOTO 1: Detail view of damaged (driver's) side of van. Point A refers to front end of rubbing strip, with dashed line showing original position of strip.

PHOTO 2: View of undamaged (passenger) side of van, showing rubbing strip which speared through car on impact side

PHOTO 3: Side view of van (undamaged side).

PHOTO 4: Front view of car showing offset impact.

PHOTO 5: Interior view of car, arrow points to hole left by rubbing strip spearing through firewall and into driver's chest.

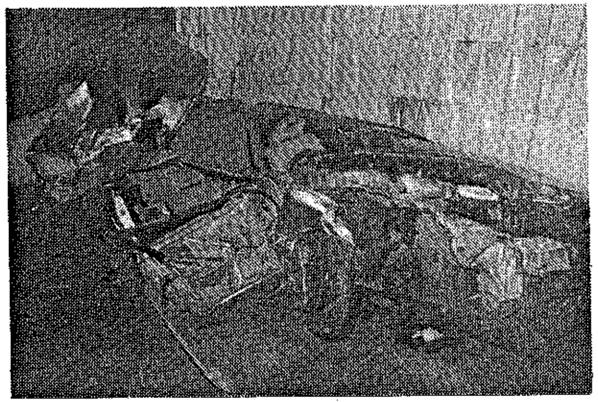


Photo F33-1 Side view of the car,
showing flattening of A-pillar and shearing of roof back to the C-pillar

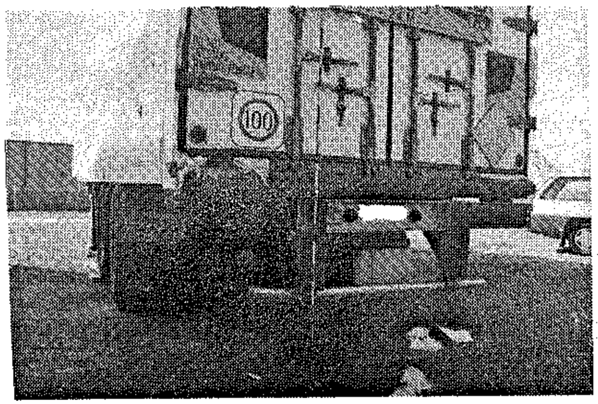
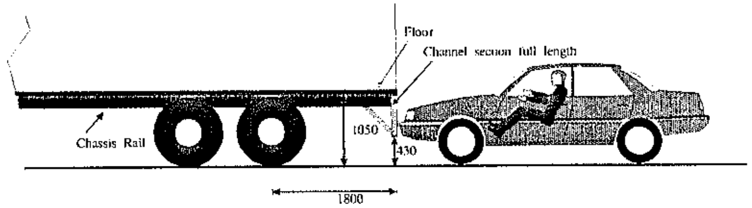
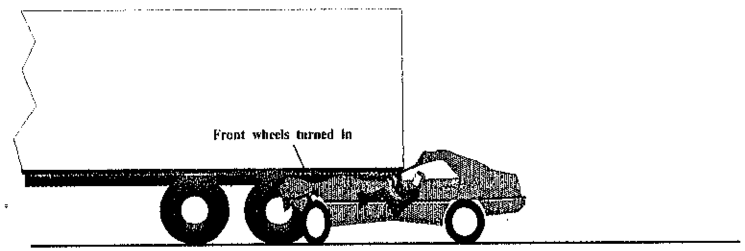


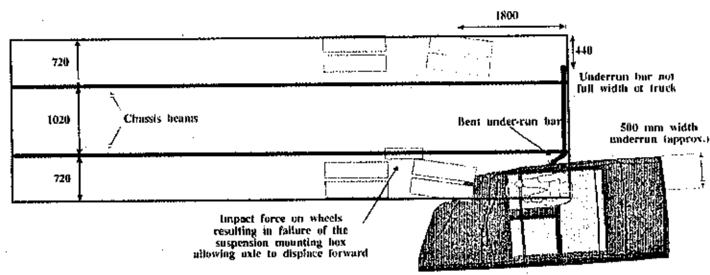
Photo F33-2 Rear view of damaged trailer. Note partial width of under-run bar and damage to the rear corner of the fibreglass body of the van.



(a) Side view prior to impact, showing car relative to rear of truck

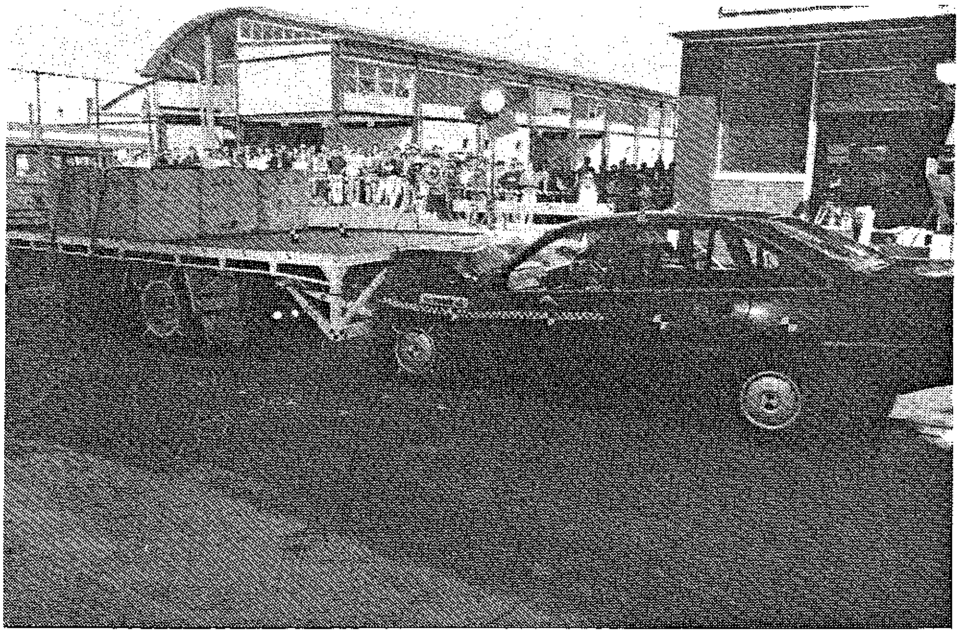


(b) Side view after impact (inferred)
Note that the rear wheel of the truck took the brunt of the impact load



(c) Plan view after impact showing (inferred) position of vehicle underriding trailer

FIGURE 6 Crash Investigations: CASE F33
Example of rear underrun crash (driver killed)



Centred, 50 kph impact test of rear underrun barrier, at moment of impact

Offset, (50%) 50 kph impact test of rear underrun barrier, at moment of impact

FIGURE 7
Crash tests of prototype rear underrun barriers on rigid trucks
Part of a development and verification program for rear underrun barrier design at Monash University, for VICROADS (refer Rechnitzer, Scott & Murray 1993).