Determining the Efficacy of Different Types of Bull Bars Fitted to Different Types of Light Vehicles

Dan Leavy, Basuki Suratno, David Black

Centre for Road Safety, Transport for NSW

Abstract

Under NSW regulations, bull bars must comply with the Australian Standard AS 4876.1–2002 *Motor vehicle frontal protection systems—Road user protection*. The Standard provides illustrations of "acceptable" and "not acceptable" bull bars. Some bull bars, typically fitted to 4WDs in rural regions, resemble the "not acceptable" bull bars. The different bull bars became a matter of contention following a NSW Police campaign targeting "non-complying" bull bars in 2014. To inform this matter, the Centre for Road Safety undertook research to compare the performance of different types of bull bars. This found that neither type of bull bar tested provided additional occupant protection in a crash, but they may have some road safety and cost benefits.

Background

A bull bar is a structure, usually constructed from steel, aluminium alloy or polymer, fitted to the front of a vehicle. Bull bars and other vehicle frontal protection systems for motor vehicles are primarily intended to reduce damage to the vehicle structure and systems in the event of either a front-end impact or an animal strike. Thomas Higgins (1994), an NRMA behavioural scientist, found that the most common reasons motorists fit a bull bar to their vehicle are:

- to protect the vehicle against damage in the event of a crash with a large animal
- to prevent an animal penetrating the windscreen and entering the driving compartment
- to reduce occupant injury resulting from the force of a crash
- to prevent the vehicle from being disabled in a remote area
- to protect against minor damage caused by careless parking.

This indicates that most people fit bull bars to protect against the consequences of an animal strike, which is more likely in rural areas where free-roaming large animals, such as kangaroos and cattle, are frequently encountered. It appears vehicle owners who operate primarily in urban areas fit bull bars primarily to protect their vehicles against minor damage from parking or low-speed crashes.

In NSW, the Road Transport (Vehicle Registration) Regulation 2007 (the Regulation) requires that vehicle frontal protection systems fitted on motor vehicles under 3.5 tonne gross vehicle mass manufactured after 1 January 2003 must comply with Australian Standard 4876.1–2002 *Motor vehicle frontal protection systems—Road user protection* (the Standard), except for Clause 3.2, which relates to pedestrian head injury criteria.

The Standard provides no technical specifications for dimensions, materials and other essential features for designing and manufacturing bull bars. Instead, it specifies general requirements that are illustrated by drawings showing typical examples of "acceptable" and "not acceptable" bull bars. Some bull bars available on the NSW market appear not to comply with the Standard because they do not conform to these general requirements, and they do look like the examples of "not acceptable" bull bars illustrated in the Standard. These types of bull bars are frequently fitted to the large 4WD-type vehicles commonly driven in rural Australia. For this reason, they are commonly referred to as "rural bull bars", while those that resemble the "acceptable" figures in the Standard are referred to as "standard" or "urban bull bars".

People living in rural areas maintain that they require the bigger rural bull bars to better protect the vehicle and its occupants against kangaroo and other animal strikes as the bull bars are larger, more resilient to damage and their profile means they prevent kangaroos from penetrating the windscreen, either by deflecting them over the roof or below and to the sides of the vehicle. Keeping a kangaroo away from a vehicle's windscreen is an important safety consideration as there is considerable evidence that an animal penetrating a windscreen in a crash can inflict serious injuries on the vehicle's occupants. Rural bull bar detractors say rural bull bars are unnecessary as the smaller, urban bull bars are just as effective at protecting the vehicle and preventing a kangaroo from penetrating a windscreen. They also maintain that fitting such a large structure to the front of a vehicle may actually increase the risk to its occupants in a crash as it could affect airbag deployment, and the vehicle's crumple zone and its ability to absorb energy in a crash.

The differences between the two types of bull bars and the interpretation of the Standard, and therefore the NSW Regulation, became a matter of contention following an enforcement campaign by NSW Police targeting "non-complying" bull bars in mid-2014. As a result of this, and to prevent manufacturers who supply rural bull bars and motorists who have fitted them to their vehicles being penalised for interpreting the Standard differently, in September 2014, the NSW Minister for Roads, Maritime and Freight issued a Ministerial Exemption Order to allow motorists to retain their bull bars, provided the bull bars were within specified tolerances. The Ministerial Order allowed Transport for NSW to review the law in NSW on bull bars. As part of this review, the Centre for Road Safety undertook the research program outlined in this paper that compared the performance of rural and urban bull bars fitted to different vehicles in a head-on crash with a large kangaroo, and the effect a rural bull bar has on a vehicle's crashworthiness.

The tests were carried out at the Roads and Maritime Services' Crashlab facility. The test protocols were developed by the Centre for Road Safety in consultation with the Crashlab technicians, and endorsed by a focus group of key stakeholders including bull bar manufacturers represented through industry associations, including the 4WD Industry Council, Australian Aftermarket Automotive Association and the Bull Bar Council; user groups from 4WD NSW & ACT Inc. and NSW Farmers; the Motor Traders Association NSW; and vehicle standard enforcement agencies, Roads and Maritime and the NSW Police Force. The tests used a kangaroo crash test dummy developed by Ford Australia, in conjunction with Melbourne Zoo, as part of Ford's vehicle-proving research program. It is believed that these were the first tests of their kind carried out anywhere in the world.

Method

General

This research program looked at the effects of fitting bull bars to vehicles:

1. How they protect vehicles and their occupants in a crash with a large animal (the primary research)
2. How they affect vehicle crashworthiness, including interfering with airbag deployment and crumple zones (the secondary research).

The primary research was intended to determine the following:

- Is a vehicle without a bull bar damaged to the extent that it is undriveable, potentially leaving the occupants stranded in a remote area?
- Are rural bull bars the only type of bull bar that can effectively protect the vehicle and eliminate this risk?
- Are rural bull bars the only type of bull bar that can effectively prevent a kangaroo smashing through the windscreen and into the occupant compartment?
- How does an urban bull bar compare with a rural bull bar in controlling these risks?

To achieve this, a series of crash tests were carried out on two different types of vehicles fitted with two different types of bull bar crashing into a kangaroo crash test dummy.

For the secondary research, two frontal offset tests, using different bull bars fitted to different vehicles, were carried out in accordance with the protocols specified by the Australasian New Car Assessment Program (ANCAP), and the results compared against the ANCAP results for the vehicle model that was tested without a bull bar.

Vehicles

The two vehicle models selected for the primary research represent vehicles commonly used in rural areas – a 4WD and a large passenger sedan. Both vehicles have different front profiles that could affect how the kangaroo dummy performed in the crash tests. The vehicles were:

- A Nissan Patrol GU, a larger 4WD vehicle with relatively higher and more vertical bonnet line, and a steeper windscreen. This vehicle's profile suggests that a kangaroo crashing into it would either be deflected under the vehicle or strike the windscreen head on with considerable force.
- A Holden Commodore VE, with a lower bonnet line, a shallower angled windscreen, and a lower ride height. This vehicle was chosen as a contrast to the Nissan Patrol in particular because its profile suggests that in a crash, a kangaroo is more likely to be deflected onto the bonnet and strike the windscreen a glancing blow. It is also popular with younger drivers in rural areas who tend to fit large rural bull bars to it.

After each test, the vehicle was assessed against the criteria for the Roads and Maritime Safety Check to determine if it was roadworthy, and repaired to restore it to a roadworthy condition. If the vehicle did not have too much damage, it was repaired and used again. Overall, due to cumulative damage, two Patrols and three Commodores were used during the primary testing program.

A Nissan Patrol GU and a Holden Rodeo were used in the secondary research.

Bull bars

The bull bars used in the tests were within the limits specified in the Ministerial Exemption Order. Typically, urban bull bars are manufactured from aluminium alloy, so the ones used in the tests were also aluminium alloy. On sedans, aluminium alloy rural bull bars are usually fitted in preference to heavier, steel rural bull bars, so aluminium alloy bull bars were used in the primary tests. The rural bull bars fitted to the 4WD vehicles used in the primary tests were steel as this reflects the most popular type fitted to 4WDs, while a steel bull bar and an aluminium alloy bull bar were used in the two secondary tests. Examples of the different vehicles and bull bars used in the primary research are shown in Figure 1.

Dummies

In all tests, 50th percentile Hybrid III male adult crash test dummies were positioned in each of the front seats. They were fully instrumented to record forces induced in their head, neck, chest, pelvis, femur and tibia. The specifications for the kangaroo dummy used in the primary research program were obtained from Ford Australia. It represents an average, fully grown male red kangaroo (*Macropus rufus*); it stood approximately 1.4 metres high and weighed approximately 75 kilograms, using materials of different density to replicate the kangaroo's anatomical structure. A kangaroo dummy can be seen in Figure 2.

Figure 1.1 Sedan with urban bull bar

Figure 1.2 4WD with rural bull bar

Figure 1. Examples of the different types of vehicles and bull bars

Primary tests

A series of tests were done on each vehicle model that had, in turn, no bull bar fitted, an urban bull bar fitted and a rural bull bar fitted. The tests simulated a head-on crash into a kangaroo at the highest and lowest points it would be likely to impact the bull bar. Each vehicle-bull bar combination was crashed into the kangaroo dummy positioned at different predetermined heights on the runway along the vehicle's centreline.

The tests were intended to determine the following:

- the trajectory of the kangaroo dummy after being struck by the vehicle
- if the vehicle's two front occupants received any injuries from the impact
- if the airbags deployed during the crash
- the effect of the kangaroo dummy striking the windscreen
- the damage the kangaroo dummy caused the vehicle
- whether the vehicle was driveable after the collision
- if the vehicle was roadworthy under the Roads and Maritime Services' Safety Check (i.e. the "Pink Slip") criteria
- the cost of returning the vehicle to a full roadworthy condition.

The speed of the vehicle at the point it struck the kangaroo dummy was set at 80 km/h in accordance with Crashlab's safety specifications. This speed was deemed appropriate for the tests as it is close to the maximum permitted speed limit on rural roads of 110 km/h, and thus allows for a driver braking from that speed prior to crashing into a large animal.

Each vehicle-bull bar combination was tested twice, with the kangaroo dummy placed so the bull bar would strike it at lower and higher points. Using research done on kangaroo locomotion when travelling at maximum velocity (Kram and Dawson 1988), the lower point was 350 mm for both types of vehicles, while the higher point was determined by the bull bar profile, which was 600 mm

for the sedan and 850 mm for the 4WD. To attain the necessary height, the dummy was placed on a sacrificial polystyrene block that did not affect the vehicle-dummy interaction. Some of these different arrangements can be seen in Figure 2.

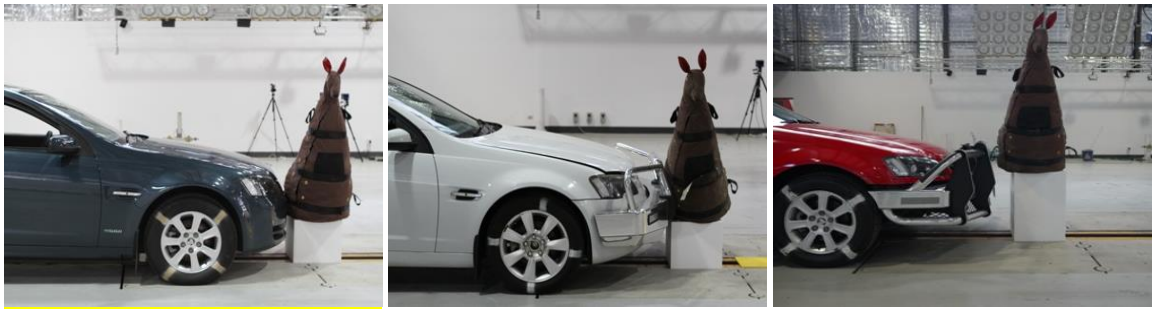

Figure 2.1 Sedan with (L-R): no bull bar, low dummy; urban bull bar, low dummy; rural bull bar, high dummy

Figure 2.2 4WD with (L-R): no bull bar, high dummy; urban bull bar, high dummy; rural bull bar, low dummy

Figure 2. Test configurations for the primary research

An additional test was done with the sedan striking the kangaroo dummy above the bull bar on an 850 mm polystyrene block so it was not deflected by the bull bar. This was used to verify the test protocols by comparing the vehicle after the test with one that had been involved in a "real-world" kangaroo strike. The damage profiles of the two vehicles were very similar, allowing for variables such as vehicle speed and position of strike, as can be seen in Figure 3.

Figure 3. Comparison of vehicles involved in a crash test (L) and a real-world crash (R)

All airbags were disabled for the primary tests to reduce the cost of repairing the vehicle between crash tests. Instead, a device to monitor airbag deployment was installed to detect if the airbag would have activated in the crash.

The different test arrangements are shown in Table 1.

Table 1. Primary test arrangements

Vehicle type	Type of bull bar	Bull bar material	Bull bar mass (kg)	Kangaroo position
Sedan	Urban	Aluminium alloy	35	Very high – 850mm
Sedan	None	N/A	N/A	Low – 350mm
Sedan	None	N/A	N/A	High – 600mm
Sedan	Urban	Aluminium alloy	35	Low – 350mm
Sedan	Urban	Aluminium alloy	35	High – 600mm
Sedan	Rural	Aluminium alloy	47	Low – 350mm
Sedan	Rural	Aluminium alloy	47	High – 850mm
4WD	None	N/A	N/A	Low – 350mm
4WD	None	N/A	N/A	High – 850mm
4WD	Urban	Steel	43	Low – 350mm
4WD	Urban	Steel	43	High – 850mm
4WD	Rural	Steel	95	Low – 350mm
4WD	Rural	Steel	95	High – 850mm

Secondary tests

Two tests were done to determine the effect fitting a rural bull bar has on a 4WD's crashworthiness, with the first on a Nissan Patrol fitted with a steel rural bull bar, and the second on a Holden Rodeo fitted with an aluminium alloy rural bull bar with addition side protection provided by brush rails. The test used the same protocols for the frontal offset test used by ANCAP in its vehicle testing procedure, the *Frontal Impact Testing Protocol*, Version 4.1, March 2004, which involves 40% of the front of the vehicle, on the driver's side, striking a deformable aluminium barrier at 64 km/h. The results were compared to those obtained in the ANCAP tests that were conducted without bull bars fitted (both these vehicles were assessed by ANCAP in 2005), which are available on the ANCAP website.

Results

Primary tests

The results of the primary tests are summarised in Table 2 below.

In addition to the above, in all instances:

- the airbags did not deploy
- the vehicle occupants received no discernible injuries
- the vehicles failed the Safety Check.

Secondary tests

Injury criteria and their associated injury risks developed by Kuppa (2004) were used to analyse the risk of injuries to head, neck, chest, upper and lower legs using the responses obtained from the instrumented dummies occupying the two front seats. The risk of injury results are presented in Table 3.

Table 2. Kangaroo tests – Summary of results

Sedan						
Bull bar	**Kangaroo position**	**Kangaroo's trajectory**	**Windscreen damage**	**Main damage**	**Driveable**	**Repair cost ($)[1]**
None	Low (350mm)	Up, over vehicle	No impact, no damage	Radiator Bonnet	No	6,245
None	High (600mm)	Bent over vehicle front impacting windscreen then upwards over vehicle	Damaged, no penetration	Engine Bonnet Windscreen	No	5,729
Urban	Low (350mm)	Up, over vehicle	No impact, no damage	Bonnet	Yes	4,242
Urban	High (600mm)	Bent over bull bar impacting windscreen then up, over vehicle	Damaged, no penetration	Windscreen Bonnet Headlights	Yes	5,150
Urban	Very high (850mm)	Did not impact bull bar. Into upper bonnet, windscreen and front roof, then up, over the vehicle	Damaged, no penetration	Bonnet Windscreen Roof	Yes	4,877
Rural	Low (350mm)	Up, over vehicle	No impact, no damage	Tyres	No	1,210
Rural	High (600mm)	Bent over bull bar into windscreen then up, over vehicle	Damaged, no penetration	Tyres Windscreen	No	3,478
4WD						
None	Low (350mm)	Into grille/bonnet then down and pushed along ground	No impact, no damage	Bonnet	Yes	6,787
None	High (850mm)	Bent over bonnet into windscreen then up, over vehicle, impacting roof on descent	Damaged, no penetration	Radiator Bonnet Windscreen	No	7,782
Urban	Low (350mm)	Into bull bar/bonnet then down and pushed along ground	No impact, no damage	Headlight Bonnet	Yes	3,740
Urban	High (850mm)	Bent over bull bar into bonnet then up, over vehicle, impacting roof on descent	No impact, no damage	Headlights Indicators Bonnet	Yes	8,034
Rural	Low (350mm)	Into bull bar/bonnet then down and under vehicle	No impact, no damage	Headlights Grille	Yes	4,169
Rural	High (850mm)	Bent over bull bar into bonnet then up, over vehicle	No impact, no damage	Headlights Grille	Yes	4,410

1 Actual cost of repairing the vehicles to pass the Roads and Maritime Services' Safety Check.

Table 3. Secondary tests results

Item	Nissan Patrol				Holden Rodeo			
	ANCAP Test [1]		Secondary Test		ANCAP Test [2]		Secondary Test	
	Values	Injury Risk[3]	Values	Injury Risk[3]	Values	Injury Risk[3]	Values	Injury Risk[3]
HIC 36[4]	463	4% of AIS 3+	408	3% of AIS 3+	821	16% of AIS 3+	458	4% of AIS 3+
Chest Compression	34.1mm	17% of AIS 3+	22.5mm	5% of AIS 3+	50.6mm	51% of AIS 3+	32.7mm	15% of AIS 3+
Chest Viscous Criterion	0.15	1% (AIS 4+)	0.08	0% AIS 4+	0.4	2% (AIS 4+)	0.14	0% AIS 4+
Neck Tension	1830N	0.0% of AIS 3+	1900N	0.0% of AIS 3+	2480N	0.0% of AIS 3+	1760N	0.0% of AIS 3+
Neck Extension	18.8Nm	0.0% of AIS 3+	39.1Nm	1% of AIS 3+	23.1Nm	0.0% of AIS 3+	9.9Nm	0.0% of AIS 3+
Femur Compression	2430N	1% of AIS 2+	7770N	15% of AIS 2+	4760N	3% of AIS 2+	4210N	3% of AIS 2+
Tibia Axial Compression	6040N	16% of AIS 2+	1770N	0% of AIS 2+	3860N	3% of AIS 2+	3260N	2% of AIS 2+
Summary of risk to the front seat occupants of the vehicle fitted with a bull bar compared to the ANCAP results	• The risk of an AIS 3+ head injury was relatively the same. • The risk of an AIS 3+ chest compression injury reduced by 33%. • A very small decrease in the chest viscous criterion, but the absolute risk of AIS 4+ injury was already low for the ANCAP test. • A small increase in the risk of AIS 3+ neck injury, but this was already low for the ANCAP test. • A substantial increase in the risk of an AIS 2+ femur injury. • A significant decrease in the risk of an AIS 2+ lower leg injury.				• The risk of an AIS 3+ head injury was reduced by 75%. • The risk of an AIS 3+ chest compression injury reduced by 70%. • There was a very small decrease in the chest viscous criterion, but the absolute risk of AIS 4+ injury was already low for the ANCAP test. • A very small decrease in the risk of AIS 3+ neck injury, but this was already low for the ANCAP test. • A very small decrease in the risk of AIS 2+ femur and tibia compression injury, but this was already low for the ANCAP test.			

1 The ANCAP results are available at http://s3.amazonaws.com/cdn.ancap.com.au/app/public/assets/8148ad5fb3318094c86f11be158d03037aaee5a6/original.pdf?1419226108

2 The ANCAP results are available at http://s3.amazonaws.com/cdn.ancap.com.au/app/public/assets/dc0b48bf5dd3d4b13da61a36c545f785cf77cda7/original.pdf?1417140235

3 AIS – Abbreviated Injury Scale: The comparative severity of injury based on a scale where "1" indicates a minor injury, such as a bruise, and "6" indicates a fatality.

4 HIC 36 – Head Injury Criteria 36: An indication of the risk of brain injury.

Discussion of secondary test results

Fitting the steel rural bull bar to the Nissan Patrol had no real overall effect on its crashworthiness compared to the ANCAP tests. Although the driver is likely to receive more extensive upper leg injuries, this is a relatively minor injury (AIS3+) and is compensated by the reduction in the risk of the more serious AIS 3+ chest compression injury and the significant decrease in risk of the driver sustaining a minor lower leg injury, also a comparatively minor AIS 2+ injury.

Fitting the alloy rural bull bar with brush rails to the Holden Rodeo improved its crashworthiness as the front-seat occupants incurred lesser risk of sustaining any injury compared to the ANCAP tests. The differences in injury data are likely caused by the rigid bull bar redistributing the crash forces and influencing the location of intrusion into the vehicle occupant compartment.

The alloy bull bar fitted to the Rodeo provided slightly more occupant protection than the steel bull bar fitted to the Patrol probably because it was more malleable and absorbed more of the force, and the brush rails strengthened the structure, reducing intrusion into the occupant compartment.

It must be emphasised that any benefits to the occupants of vehicles fitted with bull bars in a crash with another vehicle may be offset by the increased risk of injury the bull bar may pose to the occupants of the other vehicle. This comparative risk assessment was outside the scope of the research project and was not investigated.

Limitations

The research project as a whole had some limitations:

- The research project was solely focused on comparing the performance of the bull bars and is not intended to inform the fundamental design of bull bars.
- The effect on a vehicle's crashworthiness and airbag deployment in low speed crashes was not investigated.
- This research project was solely concerned with vehicle and occupant protection, and it did not cover the effect the different bull bars may have on other road users, including pedestrians and occupants of other vehicles.
- The primary tests were limited to two vehicle models and two types of bull bars. They can only be considered to provide indicative results of how the many different types of bull bars may perform when fitted to the many different types of light vehicles registered in NSW; other bull bars fitted to other vehicles may behave differently.
- The primary research focused on typical urban and rural bull bars which are usually manufactured from steel or aluminium alloy, and made no comparison of the performance of bull bars made from other materials, such as polymer plastic.
- The vehicles' impact speed in the primary tests was necessarily limited to 80 km/h as this is the maximum speed the test facility could safely accommodate.
- The vehicles were not fitted with advanced safety assist technologies, so the research project does not compare cost savings that would derive from repairing radars, cameras and other components incorporated in these technologies.

Conclusions

Primary tests

Applying the findings from the primary tests, it can be concluded that, in a real world high-speed crash into a kangaroo or similar animal:

- Fitting the types of bull bar to the vehicles used in the tests provides no additional protection to the vehicles' front seat occupants.
- Bull bars do have other road safety benefits. Occupants may become stranded if their vehicle is sufficiently damaged after a high speed animal strike, and if they leave the vehicle to seek assistance, they become exposed to the risks associated with pedestrians mixing with traffic on rural roads, which is further exacerbated in the dark. The appropriate bull bar fitted to a vehicle may prevent this occurring.
- A vehicle without a bull bar is likely to be damaged to the extent it is undriveable and strand the occupants.

- Fitting an urban bull bar to a sedan-type vehicle can reduce the damage the vehicle sustains so it remains driveable after an animal strike, and with a corresponding reduction in repair costs.
- Fitting a rural bull to a sedan-type vehicle has no road safety benefit; in fact, it presents a considerable risk as the damage the vehicle sustains could be sufficient to render the vehicle undriveable and strand its occupants.
- Fitting either an urban or a rural bull bar to a 4WD can protect the vehicle so it remains driveable after an animal strike, with a corresponding reduction in repair costs.
- A 4WD vehicle receives most benefit from a rural bull bar as the amount of damage the vehicles sustains is comparatively less than if an urban bull bar was fitted.
- A bull bar fitted to a sedan-type vehicle has little influence against the risk of a kangaroo striking the windscreen as there is a strong probability that the vehicle will strike the kangaroo at a point in its hop trajectory when it is higher than the bull bar.
- A rural bull bar fitted to a 4WD is more likely to strike a kangaroo as the vehicle's higher front profiles mean it covers more of the kangaroo's hop trajectory.
  Note: The incidence of kangaroos crashing through windscreens in real-world crashes is likely due to a number of factors, such as the vehicles travelling at higher speeds than the crash-test speed; the kangaroo being above the bull bar so it strikes the windscreen directly with greater force than if it was deflected; or the windscreen being already weakened by a small crack or fracture.

Secondary tests

Applying the findings from the secondary tests, in a real world high-speed crash, fitting a rural bull bar to a 4WD does not adversely affect its crashworthiness: it does not affect its airbag deployment, and, depending on the type of bull bar, it can improve the overall protection the vehicle provides its occupants in a high speed crash into another vehicle or substantial, solid object like a tree.

Overall

Applying the findings to the matters that initiated the research in a rural environment where there is a risk of a high-speed crash into a kangaroo or other large animal:

- There are no occupant protection benefits in fitting rural bull bars to 4WD vehicles instead of urban bull bars as both reduce the likely damage to the vehicle to the extent that it remains driveable, so the occupants are not stranded. There is some repair cost savings in fitting a rural bull bar as it provides better vehicle protection than an urban bull bar. The rural bull bar does not have a detrimental effect on a 4WD's crashworthiness in a high-speed frontal crash with another vehicle or solid object, and may even improve the level of protection to its occupants in such a crash. However, this benefit may be offset by an increased risk to the occupants of other vehicles in a crash.
- There is no safety justification for fitting rural bull bars to sedan-type vehicles. Conversely, a rural bull bar is likely to compound the damage to the vehicle to the extent that it cannot be driven, causing its occupants to be stranded.

References

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