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Rollover crashes

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ABSTRACT

This report analyses data from police reports on crashes, and from an in-depth study of rural crashes, to examine the characteristics of rollover crashes in South Australia. The risk of a single vehicle rollover crash increases markedly at higher travelling speeds and eighty per cent of these crashes in the in-depth study were initiated by the car running at least partially onto the left unsealed shoulder. Road-related countermeasures such as audio-tactile edge lining and sealed shoulders are discussed, as is the increase with travelling speed in the risk of a crash being a single vehicle rollover. The important role of seat belt wearing in protection against serious or fatal injury is confirmed yet again. The report concludes with a brief review of the literature on the design of vehicles in relation to rollover crashes, including the benefits of electronic stability control.

KEYWORDS

Overturning, Accident analysis, Literature review, Vehicle safety, Road improvement, Accident countermeasures

Summary

Rollover crashes are known to generate a number of serious injuries, and thus costly Compulsory Third Party (CTP) insurance claims, as well as fatalities. Studies have indicated a high percentage of four-wheel-drive (4WD) and people-mover vehicles involved in these crashes compared with their percentage in the vehicle population.

This report on rollover crashes is based on an analysis of South Australian data from police reports on all crashes and from an in-depth study of rural crashes.

A summary review of the literature on the design of vehicles in relation to rollover resistance is included, with particular reference to the ratio of track to height of centre of gravity and the approach adopted by the National Highway Traffic Safety Administration in the United States to the relationship between vehicle design and the risk of rollover crashes.

Rollovers that occur following a collision with another vehicle have the potential to add significantly to the severity of the injuries sustained by the occupants of those vehicles but there are even greater reasons to be concerned about single vehicle rollovers.

The risk of a single vehicle rollover crash increases markedly at higher travelling speeds, as indicated by the speed limit of the road on which the crash occurs. This adds strong support to the case for reductions in the higher speed limits in rural areas.

Eighty per cent of the single car rollover crashes in the in-depth study sample were initiated by the car running at least partially onto the left unsealed shoulder. Countermeasures such as audio-tactile edge lining and sealing the shoulder could be expected to reduce the frequency of out of lane excursions and the loss of control in those excursions that do occur.

The important role of seat belt wearing in protection against serious or fatal injury was confirmed yet again in the rollover crashes investigated in the in-depth study.

The adverse effect on lateral stability of passenger and goods loading on 4WD vehicles and passenger vans, while not identified in the data analysed in this study, has been publicised widely by the United States National Highway Traffic Safety Administration and is deserving of serious consideration in Australia.

Experience with electronic stability control (ESC) in the United States shows that it is by far the most effective vehicle-based crash preventive measure ever developed, particularly with respect to single vehicle crashes of which rollovers are a large part. It is recommended that consideration be given to allocating a substantial proportion of road safety publicity budgets to publicising the safety benefits of electronic stability control, as has been done by the Swedish Road Administration, to encourage both the provision of ESC on new vehicles and the purchase of vehicles so equipped.

As there is still no consensus about ways to assess dynamic rollover stability and the effectiveness of various electronic stability control systems, it is suggested that Australian authorities continue to monitor overseas developments before considering the introduction of any regulatory measures.

Contents

1 Introduction

Rollover crashes are known to generate a number of serious injuries, and thus costly Compulsory Third Party (CTP) insurance claims, as well as fatalities. Studies have indicated a high percentage of four-wheel-drive (4WD) and people-mover vehicles involved in these crashes compared with their percentage in the vehicle population.

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2 Police reports on rollover crashes

This section analyses the rollover casualty crash data for South Australia contained in police reports as presented in the Traffic Accident Reporting System.

The Traffic Accident Reporting System (TARS) database is maintained by the South Australian Department for Transport, Energy and Infrastructure (DTEI) and is based on crashes reported to the police. It represents the best available data on the occurrence of road crashes in South Australia.

For the current analysis, casualty crashes for the years 1999 to 2003 inclusive, as recorded in TARS, are analysed as a group. Note that the TARS data as supplied to the Centre in August 2004 was used. TARS is being constantly updated so rerunning the analyses presented here on a different version of the TARS data may produce slightly different results.

2.1 Identifying rollover casualty crashes

Unfortunately, the TARS database does not record whether or not individual vehicles involved in crashes rolled over. The only reference to rollover is in the type of crash. Each crash is classified in to one of the following types:

- Rollover
- Rear end
- Hit fixed object
- Side swipe
- Right angle
- Head on
- Hit pedestrian
- Right turn
- Hit parked vehicle
- Hit animal
- Hit object on road
- Left road - out of control
- Other
- Unknown

All casualty crashes coded as being a “rollover” crash between 1999 and 2003 were extracted and the types of the vehicles involved in each crash were identified. The results are shown in Table 2.1.

Table 2.1
"Rollover" casualty crashes - involved vehicle types
South Australia 1999-2003 (source: TARS data)

Vehicle types	Number
Car	894
Motorcycle	406
Station wagon	268
Utility	234
Semi trailer	94
Pedal cycle	84
Unknown motor vehicle	79
Panel van	55
Truck	51
Other defined motor vehicle	14
4WD (limited cases coded)	5
Omnibus	4
Forward control passenger van	1
Taxi cab	1
Multiple vehicles	38
Total	2228

For the current purposes, crashes involving a single motorcycle or a single pedal cycle are not considered to be rollover crashes and are excluded henceforth. The crashes involving a single “unknown motor vehicle” or “other defined motor vehicle” are also excluded since the vehicle may not be of a type where rollover is relevant. Since we are interested in the details of the vehicle that rolled over and particularly in single vehicle rollover crashes, the small number of “multiple vehicles” crashes are also excluded henceforth.

Table 2.2 shows the most severe injury sustained by occupants in each of the single vehicle rollover casualty crashes identified above compared to all other casualty crash types.

Table 2.2
Maximum injury severity in single vehicle rollover
casualty crashes compared to all other crash types
South Australia 1999-2003 (source: TARS data)

Maximum injury severity	Number		Column per cent	
	Rollover	Other	Rollover	Other
Treatment by private doctor	123	13178	7.7	36.6
Treatment at hospital	825	16744	51.3	46.5
Admission to hospital	590	5490	36.7	15.2
Fatal	69	623	4.3	1.7
Total	1607	36035	100.0	100.0

Clearly rollover casualty crashes tend to produce more severe injuries than other crash types. Since less than 8 per cent of rollover casualty crashes only require treatment by a private doctor, and we are interested particularly here in severe injuries, the remaining analyses will concentrate on single vehicle rollover crashes where an occupant of the vehicle was treated or admitted to hospital or fatally injured.

As an aside, the crash injury severity of all crashes reported to the police with an injury or property damage of $1,000 or greater were examined for the years 1999-2002 (property damage only crashes were not fully coded in 2003). The result shown in Table 2.3 indicate that half of all such single vehicle rollover crashes in South Australia result in an injury compared to only 18 per cent of other crash types.

Table 2.3
Maximum injury severity of single vehicle rollover crashes compared to all other crash types
South Australia 1999-2002 (source: TARS data)

Maximum injury severity	Number		Column per cent	
	Rollover	Other	Rollover	Other
Property damage only	1338	131693	50.4	81.8
Treatment by private doctor	106	10770	4.0	6.7
Treatment at hospital	681	13520	25.7	8.4
Admission to hospital	472	4441	17.8	2.8
Fatal	56	501	2.1	0.3
Total	2653	160925	100.0	100.0

2.2 Single vehicle rollover crashes resulting in at least treatment in hospital

This section examines the identified 1,484 single vehicle rollover crashes in South Australia between 1999 and 2003 that resulted in at least one occupant requiring treatment at hospital or being fatally injured.

2.2.1 Injury severity

Table 2.4 indicates that 6.1 per cent of all crashes in South Australia that resulted in a person needing hospital treatment or being fatally injured involved a single vehicle that rolled over. This percentage increases for higher crash injury severity levels up to the point where 10 per cent of fatal injury crashes involved a single vehicle rolling over.

Table 2.4
Crash injury severity of single vehicle rollover casualty crashes resulting in an occupant being treated at hospital or fatally injured compared to crash injury severity of all other crash types
South Australia 1999-2003 (source: TARS data)

Crash injury severity	Rollover	Other	% Rollover
Treatment at hospital	825	16744	4.7
Admission to hospital	590	5490	9.7
Fatal	69	623	10.0
Total	1484	22857	6.1

Table 2.5 indicates that 6.6 per cent of all hospital treated or fatally injured casualties in South Australia were in a single vehicle that rolled over. This is a higher percentage than that for casualty crashes as single vehicle rollover hospital crashes tended to have more hospital casualties per crash than other crash types (although less fatalities).

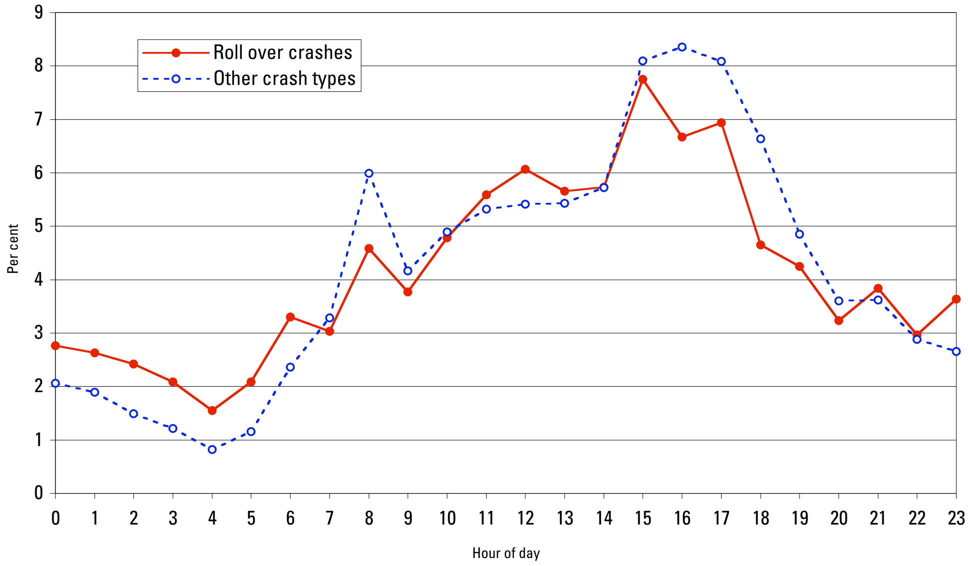
Table 2.5
Injury severity of single vehicle rollover crash occupants compared to injury severity of all other crash type casualties
(treated at hospital or fatally injured)
South Australia 1999-2003 (source: TARS data)

Injury severity	Rollover	Other	% Rollover
Treatment at hospital	1347	23643	5.4
Admission to hospital	810	7035	10.3
Fatal	74	708	9.5
Total	2231	31386	6.6

2.2.2 Time of crash

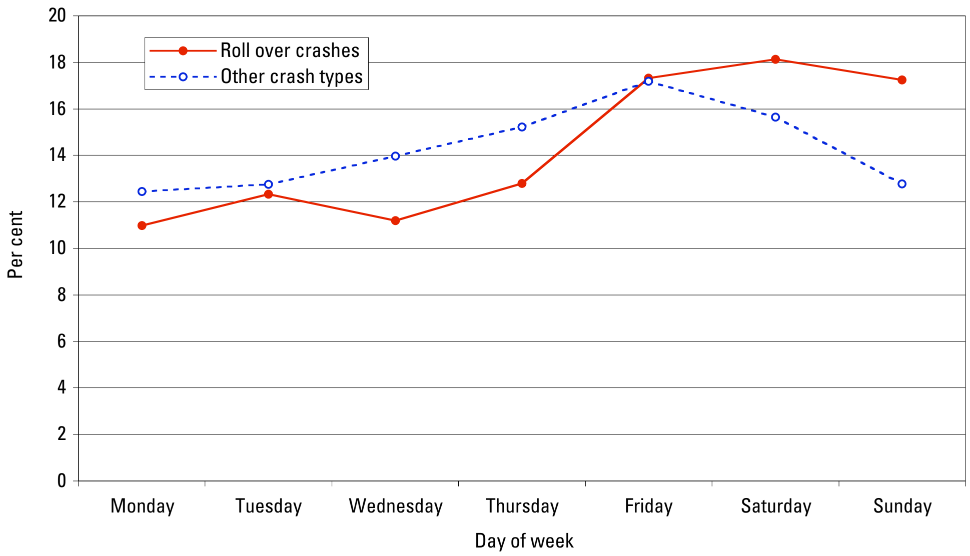
The distribution of time of day for rollover hospital crashes is compared to that for other hospital crash types in Figure 2.1. The distributions are similar with the main differences being lower morning and afternoon peaks for rollover crashes and rollover crashes playing a greater role after 11pm into the early hours of the morning.

Figure 2.1
Hour of day of single vehicle rollover crashes compared to all other crash types for crashes resulting in an occupant being treated at hospital or fatally injured South Australia 1999-2003 (source: TARS data)



The distribution of day of week for rollover hospital crashes is compared to that for other hospital crash types in Figure 2.2. Rollover crashes play a greater role on Saturdays and Sundays.

Figure 2.2
Day of week of single vehicle rollover crashes compared to all other crash types for crashes resulting in an occupant being treated at hospital or fatally injured South Australia 1999-2003 (source: TARS data)



The distribution of crash lighting conditions for rollover hospital crashes is compared to that for other hospital crash types in Table 2.6. Rollover hospital crashes are slightly more likely to happen at night or at dawn/dusk compared to other hospital crash types.

Table 2.6
Lighting conditions of single vehicle rollover crashes compared to all other crashes for crashes resulting in persons being treated at hospital or fatally injured South Australia 1999-2003 (source: TARS data)

Lighting conditions	Number		Column per cent	
	Rollover	Other	Rollover	Other
Daylight	963	15743	64.9	68.9
Night	466	6420	31.4	28.1
Dawn/dusk	55	694	3.7	3.0
Total	1484	22857	100.0	100.0

2.2.3 Location of crash

Table 2.7 shows the general geographic location of single vehicle rollover crashes compared to all other crash types. The great majority of single vehicle rollover crashes occur outside the Adelaide statistical division (the Adelaide Plains area) and in fact account for 18.3 per of crashes there.

Table 2.7
Location of single vehicle rollover crashes compared to all other crashes for crashes resulting in persons being treated at hospital or fatally injured South Australia 1999-2003 (source: TARS data)

Location of crash	Rollover	Other	% Rollover
Inner Adelaide Area	1	1482	0.1
Adelaide Statistical Division	182	15556	1.2
Outside of Adelaide	1301	5819	18.3
Total	1484	22857	6.1

Table 2.8 shows roads which averaged 2 or more single vehicle rollover hospital crashes per year. These roads account for nearly half (48.2%) of all single vehicle rollover hospital crashes in South Australia. Note that these roads may not be particularly conducive to vehicles rolling over. They all tend to be long high speed roads with high traffic flows.

Table 2.8
Roads which average two or more
single vehicle hospital rollover crashes per year
South Australia 1999-2003 (source: TARS data)

Road name	Rollover crashes 1999-2003	Average rollover crashes per year
Stuart Highway	85	17.0
Princes Highway	53	10.6
Port Wakefield Road	50	10.0
Eyre Highway	49	9.8
Barrier Highway	45	9.0
Port Augusta - Port Wakefield	39	7.8
Sturt Highway	39	7.8
South East Highway	38	7.6
Dukes Highway	32	6.4
Lincoln Highway	32	6.4
Noarlunga - Cape Jervis	27	5.4
Main North Road (Country)	26	5.2
Keith - Mount Gambier	25	5.0
North East Road	22	4.4
Flinders Highway	19	3.8
Port Wakefield - Yorketown	19	3.8
South Road	18	3.6
Moorlands - Pinnaroo	17	3.4
Main North Road	16	3.2
Granite Downs - Marree	15	3.0
Loxton - Murray Bridge	15	3.0
Blackwood - Goolwa Rd	14	2.8
Gorge Road	10	2.0
Noarlunga - Victor Harbor	10	2.0
Total	715	143.0

2.2.4 Road alignment

Although most single vehicle rollover hospital crashes occur on straight sections of road (Table 2.9) and on sections of road that are level (Table 2.10) they are more likely to be on curved and non-level sections of road than other crash types.

Table 2.9
Horizontal road alignment at location of single vehicle rollover crashes compared to all other crashes
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Horizontal road alignment	Number		Column per cent	
	Rollover	Other	Rollover	Other
Straight road	850	19451	57.3	85.1
Curved road	625	3371	42.1	14.7
Unknown	9	35	0.6	0.2
Total	1484	22857	100.0	100.0

Table 2.10
Vertical road alignment at location of single vehicle rollover crashes compared to all other crashes
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Vertical road alignment	Number		Column per cent	
	Rollover	Other	Rollover	Other
Level	1077	18699	72.6	81.8
Slope	248	3011	16.7	13.2
Crest of Hill	108	672	7.3	2.9
Bottom of Hill	41	424	2.8	1.9
Unknown	10	51	0.7	0.2
Total	1484	22857	100.0	100.0

2.2.5 Speed limit at crash location

Most single vehicle rollover hospital crashes occur on high speed roads and account for nearly one third of crashes on 110 km/h roads (Table 2.11).

Table 2.11
Speed limit at location of single vehicle rollover crashes compared to all other crashes
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Location of crash	Rollover	Other	% Rollover
60	112	14995	0.7
70	13	754	1.7
80	94	1827	4.9
90	16	191	7.7
100	438	1878	18.9
110	783	1774	30.6
Other/unknown	28	1438	1.9
Total	1484	22857	6.1

2.2.6 Vehicle types

While cars and station wagons account for the majority of single vehicle rollovers, it appears that utilities/4WDs and trucks are over represented compared to other crash types (Table 2.12).

Table 2.12
Type of vehicles involved in single vehicle rollover crashes
compared to vehicles involved in all other crash types
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Vehicle type	Rollover	Other	% Rollover
Car	826	25404	3.15
Station wagon	248	4496	5.23
Utility/4WD	223	1855	10.73
Truck	131	1248	9.50
Panel van	51	1074	4.53
Other	5	234	2.09
Total	1484	34311	4.15

2.2.7 Police recorded cause of crash

The most common police recorded causes of single vehicle rollover crashes are inattention, driving under the influence of alcohol, vehicle faults and excessive speed (Table 2.13). These causes are all much less prominent in other crash types.

Table 2.13
Police recorded cause of crash of single vehicle rollover crashes compared to all other crashes
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Police cause of crash	Number		Column per cent	
	Rollover	Other	Rollover	Other
Inattention	1106	9339	74.5	40.9
Driving under the influence of alcohol or drugs	155	1276	10.4	5.6
Vehicle fault	84	197	5.7	0.9
Excessive speed	51	419	3.4	1.8
Died sick or asleep at wheel	38	384	2.6	1.7
Overtake without due care	10	356	0.7	1.6
Brake failure	3	26	0.2	0.1
Dangerous driving	2	27	0.1	0.1
Other	35	10833	2.4	47.4
Total	1484	22857	100.0	100.0

2.2.8 Driver factors

Table 2.14 shows that there is no difference in the sex of the driver involved in single vehicle Rollover crashes compared to other crash types (chi square = 0.73, NS).

Table 2.14
Sex of drivers involved in single vehicle rollover crashes
compared to drivers involved in all other crash types
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Sex of driver	Rollover	Other	% Rollover
Male	928	20914	4.2
Female	555	13109	4.1
Unknown	1	288	0.3
Total	1484	34311	4.1

Figure 2.3 shows the age distribution of drivers involved in single vehicle rollover crashes compared to drivers in other crash types. The distributions are remarkably similar apart from an apparent over representation of drivers aged 16 to 18 in single vehicle rollover crashes.

Figure 2.3
Age of drivers involved in single vehicle rollover crashes
compared to drivers involved in all other crash types
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

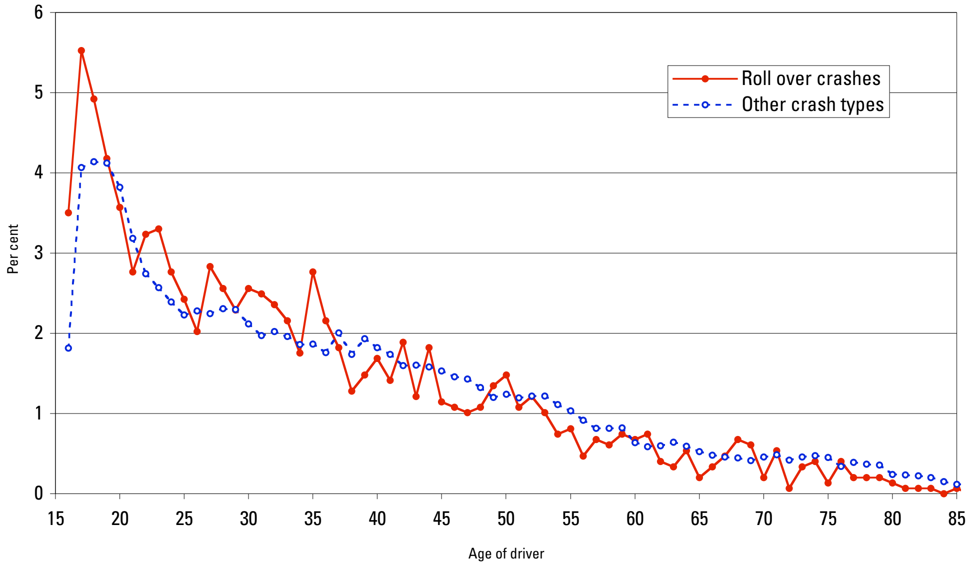


Table 2.15 indicates that crashes involving provisional, and in particular learner drivers, are more likely to be single vehicle roll overs than is the case for crashes involving full licence holders. Unlicensed drivers are also over represented to an even greater extent. However, the large proportion of unknown licence types in other crash types and in particular roll over crashes does suggest some caution in interpreting these results.

Table 2.15
Licence status of drivers involved in single vehicle rollover crashes
compared to drivers involved in all other crash types
for crashes resulting in persons being treated at hospital or fatally injured
South Australia 1999-2003 (source: TARS data)

Licence status	Rollover	Other	% Rollover
Learners	25	280	8.2
Provisional	220	4149	5.0
Full	851	26174	3.1
Unlicensed	12	127	8.6
Unknown	376	3581	9.5
Total	1484	34311	4.1

2.3 Summary

In summary, an analysis of the available TARS data on single vehicle rollover crashes compared to other crash types that resulted in at least one occupant requiring treatment at hospital or being fatally injured found that rollover crashes were:

- more likely to produce casualties
- more likely to produce a greater number of casualties in a given vehicle
- more likely to produce more serious casualties
- roughly similar in terms of time of day but with lower morning and evening peaks and a greater representation in the late night and early morning hours
- more likely on the weekend
- slightly more likely at night or at dawn/dusk
- mostly on rural high speed roads
- over represented on curved sections of road and on slopes, crests and dips
- more likely for utilities/4WDs and trucks
- primarily attributed by the police to inattention but also to driving under the influence of alcohol or drugs, vehicle faults and excessive speed
- representative of all crashes in terms of the sex of the driver
- more likely to involve drivers age 16 to 18 years old who were learner or provisional licence holders

3 In-depth investigations of rollover crashes

This section reviews the information collected on rollover crashes in an in-depth investigation of rural crashes occurring within 100 km of Adelaide.

3.1 Characteristics of the sample of crashes

A series of 236 rural road crashes to which an ambulance was called was investigated by the Road Accident Research Unit (now the Centre for Automotive Safety Research) between March 1998 and February 2000. Unit personnel attempted to reach the scene of the crash before the vehicles were moved. Vehicle positions and damage were recorded and the site was mapped and photographed. Participants and witnesses were interviewed in most cases, either at the scene or in follow up interviews. In some fatal cases, where the vehicle positions had been marked by the Police Major Crash Investigation Section, the investigating team examined the crash scene within 24 hours. This had the effect of increasing the number of fatal crashes in the sample.

The sample of crashes investigated is not fully representative of all crashes occurring in the study area because the investigating teams were on call more frequently during daylight hours from Monday to Friday than on weekends. Similarly, night time crashes were under represented, apart from Thursday and Friday nights. However, characteristics associated with single vehicle rollover crashes can reasonably be compared with corresponding characteristics associated with other types of crash in this sample.

It should also be recognised that comparisons with the TARS data which has been presented in Section 2 are influenced by the inclusion of crashes in the metropolitan area of Adelaide in the State-wide data and by differences due to the study area including most of the hill country in the State.

3.1.1 Rollovers alone and after a collision

Sixty four of the 236 crashes resulted in a vehicle rolling over. There were 19 cases in which a vehicle rolled without any prior collision. Another 21 of these rollovers occurred following a collision with another vehicle and in the remaining 24 single vehicle rollover crashes the vehicle rolled after a collision with a tree or an embankment (Table 3.1). However, it should be noted that in many of these single vehicle rollovers after a collision with a fixed object it is probable that the vehicle would have rolled over in any event had the collision not occurred.

Table 3.1
Rollover crashes and prior collisions

Prior collisions	Number of crashes
No prior collision	19
Collision with fixed object	24
Collision with other vehicle	21
Total	64

3.1.2 Road alignment and speed limit

Almost half (49%) of the single vehicle rollover crashes occurred on straight sections of road, with about two thirds of the remainder on right hand curves (Table 3.2). The percentage on straight roads was slightly higher in the TARS cases (57%; Table 2.9). This may be due to chance variation but also to the topography of the in-depth study area. As noted above, it covered a much higher proportion of hill terrain than the whole State, which is mainly flat and hence with mostly straight roads. The vehicle movements on straight roads that typically result in rollover are described later in this section.

Table 3.2
Road alignment in single vehicle rollover crashes compared to all other crash types

Road alignment	Rollover	Other	Column % Rollover	Column % Other
Straight	21	117	48.8	60.6
Right curve	13	45	30.2	23.3
Left curve	9	31	20.9	16.1
Total	43	193	100.0	100.0

The default open road speed limit in South Australia is 100 km/h, with most major highways zoned at 110 km/h. Consequently, it is not surprising that over 80% of these single vehicle rollover crashes occurred on roads having a speed limit of at least 100 km/h (Table 3.3). However, as noted above, the topography of the study area included a high proportion of hill terrain and so eight of the single vehicle rollover crashes on 100 km/h roads occurred on bends having a posted advisory speed ranging from 25 to 80 km/h. Two of the 16 crashes on 110 km/h roads occurred on bends where an advisory speed was posted (65 and 75 km/h).

Eighty one per cent of these single vehicle rollover crashes occurred on 100 or 110 km/h roads. This is very close to the State-wide figure of 84% for single vehicle rollover crashes (Table 2.11). Single vehicle rollover crashes increase as a percentage of all crashes at the higher speed limits, both in the in-depth study data and the Statewide TARS data, to the extent that 30% of all crashes on 110 km/h speed limit roads are single vehicle rollovers, compared with less than 20% on 100 km/h roads (Table 3.3).

The two crashes which occurred on 60 km/h roads were unusual in that one involved a rigid truck on which the load shifted when cornering and the other an elderly driver whose car ran up onto an embankment for no apparent reason and rolled over.

Some of these crashes were included in a case control study of travelling speed and the risk of crash involvement and so the travelling speed of the vehicle which rolled over was estimated. There were two crashes on 100 km/h speed limit roads where the cars were estimated to have been exceeding the limit by a wide margin (travelling speeds of 150 and 170 km/h).

Table 3.3
Speed limit by percentage of single vehicle rollover crashes: In-depth study and State wide

Speed limit	Rollover crashes	Other crashes	% Rollover	% Rollover TARS*
60 km/h	2	32	5.9	0.7
70 km/h	2	4	33.3	1.7
80 km/h	2	32	5.9	4.9
90 km/h	2	7	2.2	7.7
100 km/h	19	81	19.0	18.9
110 km/h	16	37	30.2	30.6
Total	43	193	18.2	6.1

* Note: From Table 2.11

3.1.3 Type of vehicle

A car or car derivative (station wagons and some utilities) accounted for almost three fifths of the vehicles which rolled over in the 64 crashes (Table 3.4, note that two vehicles rolled over in one crash). What is more interesting, given the relative numbers of vehicles on the roads, is the high percentage (24.6%) of 4WD vehicles, and the fact that three of these 4WD vehicles were towing trailers. The percentage of semi trailers in Table 3.4 (10.8%) may be accounted for in part by the comparatively high exposure of these vehicles in terms of distance travelled but their crash circumstances demonstrated a marked deficit in lateral stability compared to other types of vehicle.

Table 3.4
Type of vehicle in all crashes resulting in a rollover

Type of vehicle	Number of vehicles	% of vehicles
Car or car derivative	38	58.5
Semi trailer	7	10.8
Light van	1	1.5
Rigid truck	3	4.6
4WD (three towing a trailer)	16	24.6
Total	65	100.0

Note: Two vehicles rolled in one crash (semitrailer & 4WD)

The percentage of 4WDs among those vehicles which rolled following a collision with another vehicle (31.8%) was higher than it was for single vehicle rollovers (20.9%) (Tables 3.5 and 3.6). Conversely, cars were much less likely to be the vehicle which rolled following a collision (45.5%).

Table 3.5
Type of vehicle rolling over after colliding with another vehicle

Type of vehicle	Number of vehicles	% of vehicles
Car or car derivative	10	45.5
Semi trailer	3	13.6
Rigid truck	2	9.1
4WD (one towing a trailer)	7	31.8
Total	22	100.0

Note: Two vehicles rolled in one crash (semi trailer & 4WD)

Two thirds of the crashes in which a vehicle rolled over involved only that vehicle and almost two thirds (65.1%) of the vehicles in these single vehicle rollovers were cars or car derivatives (Table 3.6). The relative involvement of cars compared to other vehicles (mostly 4WDs) differed markedly however depending on whether the vehicle struck a fixed object, usually a tree, before rolling over. In that case, 83.3% of the vehicles were cars whereas the corresponding percentage for cars in rollover crashes without prior impact was 42.1% (Tables 3.8 and 3.7, respectively). This does not mean that none of the cars which rolled following a collision with a fixed object would not have rolled had that collision not have occurred. As mentioned in Section 3.1.1, it is likely that a rollover would still have occurred in many of these cases. The evidence for this is presented later in this Section of the report.

The numbers of cases involving 4WD vehicles in Tables 3.7 and 3.8 are too small to provide a reliable comparison with the corresponding data for cars presented in the previous paragraph but the percentages are consistent with 4WD vehicles rolling over before they have travelled out of control far enough to collide with a fixed object.

Table 3.6
Type of vehicle in single vehicle rollover crashes

Type of vehicle	Number of vehicles	% of vehicles
Car or car derivative	28	65.1
Semi trailer	4	9.3
Light van	1	2.3
Rigid truck	1	2.3
4WD (two towing a trailer)	9	20.9
Total	43	100.0

Table 3.7
Type of vehicle in single vehicle rollover crashes
without prior collision with a fixed object

Type of vehicle	Number of vehicles	% of vehicles
Car or car derivative	8	42.1
Semi trailer	3	15.8
Rigid truck	1	5.3
4WD (two towing a trailer)	7	36.8
Total	19	100.0

Table 3.8
Type of vehicle in single vehicle rollover crashes
with a prior collision with a fixed object

Type of vehicle	Number of vehicles	% of vehicles
Car or car derivative	20	83.3
Semi trailer	1	4.2
Light van	1	4.2
4WD	5	26.3
4WD (towing a trailer)	2	10.5
Total	24	100.0

The percentage of each of the above types of vehicle involved in a single vehicle rollover is compared with all vehicles of that type involved in the crashes investigated in the in-depth study in Table 3.9. The two types of vehicle that have by far the highest rate of single vehicle rollover, given involvement in a crash, are 4WDs and semi trailers. This is consistent with the corresponding State-wide TARS data, as far as the types of vehicle can be compared. Once again, the higher percentage of all types of vehicle involved in single vehicle rollovers in the in-depth study is probably mainly a reflection of differences in topography.

Table 3.9
Type of vehicle in single vehicle rollover crashes
compared to vehicles involved in all other crash types and TARS data

Type of vehicle	Rollover	Other	% Rollover	% Rollover TARS[1]
Car	28	247	10.2	3.6
4WD	9[2]	25[3]	26.5	10.7
Semi trailer	4	13	23.5	-
Rigid truck	1	14	6.7	-
Van	1	15	6.3	4.5
Total	43	314	12.0	4.15
All trucks	5[4]	27[4]	15.6[4]	9.5

Notes: [1] From Table 2.12; [2] Two towing a trailer; [3] One towing a trailer; [4] Included above

3.1.4 Driver characteristics

The age distribution of the drivers involved in single vehicle rollover crashes was very similar to that for all other drivers in this sample of crashes. There were eight drivers under 20 years of age and they were all on Provisional licences. They represented 18.6% of all of these 43 drivers, slightly more than the 14.4% of those drivers in this age group involved in the other types of crash in this study sample. Overall, however the percentage of drivers under 30 years of age was almost exactly the same in both groups of drivers (37.2% for those in single vehicle rollovers and 37.7% for the remainder). This is consistent with the results from the TARS data, which showed little difference in the age distribution of these two groups of drivers apart from an apparent over representation of drivers in the 16 to 18 year age range. (Figure 2.3)

There were more male than female drivers involved in single vehicle rollover crashes but the difference was small (55.8% were male) and less than for the other types of crash in the in-depth study sample (62.6%). There was some difference in the percentage of all male drivers in this sample who were involved in single vehicle rollover crashes compared with other types of crash (10.9%) and the corresponding percentage for female drivers (14.0%) but it was not statistically significant (p=0.389, Chi square=0.74). The corresponding percentages for the State-wide single vehicle crash data were 4.2% and 4.1% (Tables 3.10 and 2.14).

Table 3.10
Sex of drivers involved in single vehicle rollover crashes
compared to drivers involved in all other crash types

Sex of driver	Rollover	Other	% Rollover
Male	24	196	10.9
Female	19	117	14.0
Total	43	313	12.1

Drivers operating on a Provisional licence had a higher rate of involvement in single vehicle crashes than in other types of crash but not to a statistically significant degree (Table 3.11). However, a slightly larger difference was observed in the TARS data (Table 2.15) and it was statistically significant, as would be expected with the much larger number of cases.

Table 3.11
Licence status of drivers involved in single vehicle rollover crashes
compared to drivers involved in all other crash types and TARS data

Licence status	Rollover	Other	% Rollover	% TARS
Learner	-	-	-	8.2
Provisional	8	45	15.1	5.0
Full	35	275	11.3	3.1
Unlicensed	-	-	-	8.6
Total	43	313	12.1	4.1

3.1.5 Injury severity

Injury severity is expressed here in terms of the level of treatment required or, for fatal cases, the outcome. The maximum injury severity distribution in these single vehicle rollover crashes is shown in Table 3.12.

Table 3.12
Maximum injury severity in single vehicle rollover crashes

Maximum injury severity	Number of crashes	% of crashes
Property damage only*	9	20.9
Treatment at hospital	18	27.9
Admission to hospital	14	32.6
Fatal	8	18.6
Total	43	100.0

*Note: Includes some cases involving injuries treated by private doctor

The percentage of fatal crashes is larger than would be expected in a representative sample of crashes for the reason noted at the beginning of this section.

The comparison of the distribution of injury severities between single vehicle rollover crashes and other crashes shown in Table 3.13 provides a more meaningful assessment of the importance of single vehicle rollover crashes. Bearing in mind that the criterion for entry into this sample of crashes was that an ambulance be called, it is notable that over one third of all of the occupants involved did not require ambulance transport (36.3% of the 571 occupants). However less than 20% of the occupants in single vehicle rollover crashes were in that category compared with 38% of vehicle occupants in other types of crash (p=0.004, Chi square=8.12). This difference was accounted for mainly by a higher percentage of the rollover cases requiring treatment at hospital, but not admission, and a higher percentage who were fatally injured. In other words, occupants in a single vehicle rollover were more likely to be injured to a degree requiring transport to hospital by ambulance but no more likely to be admitted to hospital. The higher percentage of rollover cases who were fatally injured was within the bounds of chance variation.

Table 3.13
Injury severity of occupants in single vehicle rollover crashes
compared to occupants involved in all other crash types

Injury severity	Rollover	Other	Column % Rollover	Column % Other
Property damage only*	12	195	19.7	38.2
Treatment at hospital	22	127	36.1	24.9
Admission to hospital	18	138	29.5	27.1
Fatal	9*	50	14.8	9.8
Total	61	510	100.0	100.0

*Note: Includes some cases involving injuries treated by private doctor and two occupants of one car were fatally injured

There was no meaningful difference in the maximum injury severity distributions between single vehicle rollover crashes with and without a collision with a fixed object but the number of cases was small in each group.

3.1.6 Seat belt use, injury severity and ejection

Eighty per cent of the most severely injured occupants (the most severely injured in each of the single vehicle rollover crashes) were wearing a seat belt in the crash, based on the 40 out of 43 crashes for which this information was available. There was a clear negative association between belt use and injury severity, as can be seen in Table 3.14. Comparing admission to hospital and fatal with less severe and no injury with respect to belt use yielded a statistically different difference (p=0.033, Chi square (corrected)=4.57).

Table 3.14
Maximum injury severity of occupants in single vehicle rollover crashes by seat belt use

Maximum injury severity	Belt worn	Belt not worn	Belt use unknown	% Worn (known)
Property damage only*	9	-	-	100.0
Treatment at hospital	11	1	-	91.7
Admission to hospital	19	4	1	69.2
Fatal	3	3	2	50.0
Total	32	8	3	80.0

*Note: Includes some cases involving injuries treated by private doctor

Similarly, four of the eight most severely injured occupants per vehicle who were not wearing a seat belt were ejected in the crash, compared with none of the 31 who were wearing a seat belt (Table 3.15).

Table 3.15
Occupant ejection from the vehicle in single vehicle rollover crashes by seat belt use

Ejection	Belt worn	Belt not worn	Belt use unknown	% Worn (known)
Yes	-	4	1	0.0
No	31	4	-	88.6
Unknown	1	-	2	-
Total	32	8	3	80.0

Finally, the five ejected occupants included three of the seven fatalities for whom ejection status could be determined (Table 3.16).

Table 3.16
Maximum injury severity of occupants in single vehicle rollover crashes by ejection from the vehicle

Maximum injury severity	Ejected	Not ejected	Ejection unknown	% Ejected (known)
Property damage only*	-	9	-	0.0
Treatment at hospital	1	10	1	9.1
Admission to hospital	1	12	1	7.7
Fatal	3	4	1	42.9
Total	5	35	3	12.5

*Note: Includes some cases involving injuries treated by private doctor

3.1.7 Vehicle movements preceding rollover

CARS AND CAR DERIVATIVES

Most of the cars involved in single vehicle rollovers in this sample of crashes were travelling on a straight road (Table 3.17). Two of these crashes were not relevant to this consideration of vehicle movements preceding rollover. One simply involved a car running off the road and along an embankment for no apparent reason. The elderly driver ceased driving following that accident. Another crash was thought probably to have been intentional.

Table 3.17
Cars in single vehicle rollover casualty crashes
by road alignment and initial and final off road excursion

Road alignment	Initial off road excursion on:		Final off road excursion on:	
	Left	Right	Left	Right
Straight	12 (4)[1]	2 (1)	5	4
Right curve	6 (2)	2 (2)	3	1
Left curve	3 (2)	1	1	1
Total[2]	21(8)	5 (3)	9	6

Notes:
[1] Number in parentheses indicates that the initial off road excursion was also the final one
[2] Two cases have been omitted (see text)

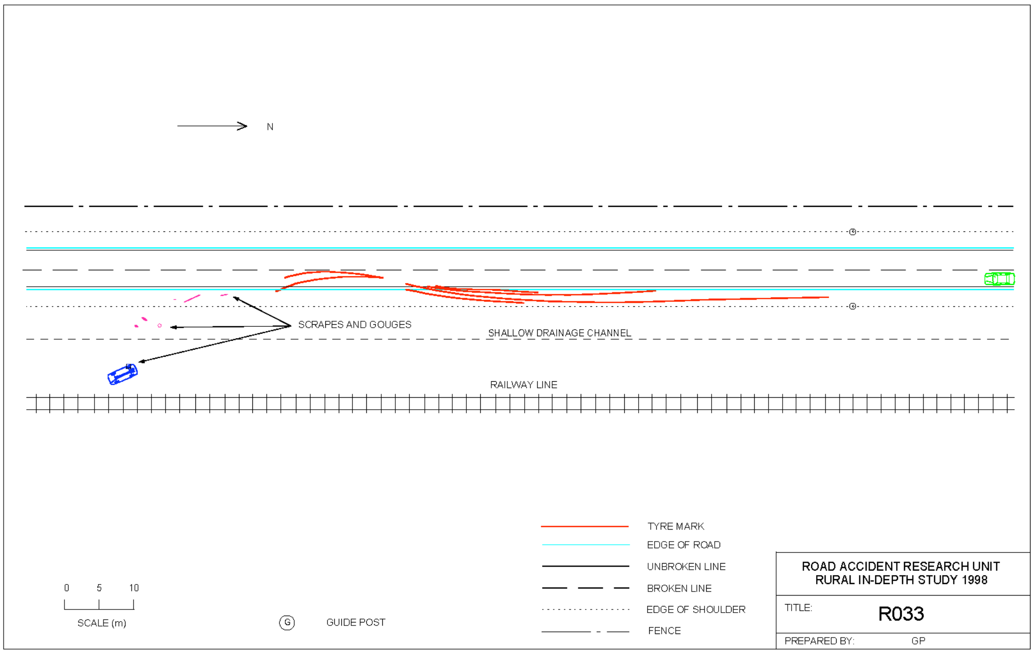
In every case the car that rolled over yawed out of control before rolling. Figures 3.1 to 3.2 show a typical single car rollover crash, the yaw marks from the tyres being clearly visible. The end of these marks indicates the point at which the car rolled to a degree where the tyres were no longer in contact with the road. The vehicle movement that precipitated the loss of control was running gradually across to the left until the left hand wheels ran onto the unsealed gravel shoulder and the driver swerved back to the right and then overcorrected to the left, as shown in the site diagram. (Figure 3.3)

There were more single car rollovers on right hand rather than left hand curves, but together they still accounted for fewer crashes than the single car rollovers on straight sections of road (Table 3.17).

Figure 3.1
Car in final position after rollover
Tyre yaw marks from right hand side wheels clearly visible
Case R033 (see text)

Figure 3.2
Damage to car after rollover
Case R033 (see text)

Figure 3.3
Site diagram showing tyre marks from initial off road excursion and overcorrection back to the left. Case R033 (see text)



4WDS IN SINGLE VEHICLE ROLLOVERS

There were nine single vehicle rollovers involving a 4WD vehicle. In one of these the vehicle rolled on a winding downhill section of a divided highway but, despite rolling several times, remained on the two lanes for traffic in its direction of travel. There were also two cases in which the initial loss of control was either precipitated by, or strongly influenced by, a trailer which was being towed by the 4WD vehicle. One of these two crashes occurred on a straight road when the trailer began to oscillate behind the short wheelbase 4WD and the other on a gradual left hand curve during an overtaking manoeuvre.

The number of cases involving 4WDs is too small to provide a reliable basis for comparison with single vehicle rollovers involving cars but two thirds of the 9 cases occurred on curves whereas less than half of the car crashes were initiated on curves (Table 3.18).

Table 3.18
4WDs in single vehicle rollover casualty crashes
by road alignment and initial and final off road excursion

Road alignment	Initial off road excursion on:		Final off road excursion on:	
	Left	Right	Left	Right
Straight	2 (1)[1]	1 (1)	1	-
Right curve	1 (1)	-	-	-
Left curve[2]	3 (2)	1	1	1
Total	6 (4)	2 (1)	2	1

Notes:
[1] Number in parentheses indicates that the initial was also the final off road excursion
[2] There was one case, not listed here, in which the vehicle rolled on a winding road without leaving the paved roadway

Figures 3.4 to 3.6 illustrate a case in which a 4WD went out of control on a divided highway on a rainy night for reasons which could not be determined. It yawed clockwise onto a grassed median, eventually rolling several times before coming to rest on its roof.

Figure 3.4
Site diagram showing tyre and roll marks and
the final position of the vehicle. Case R108 (see text)

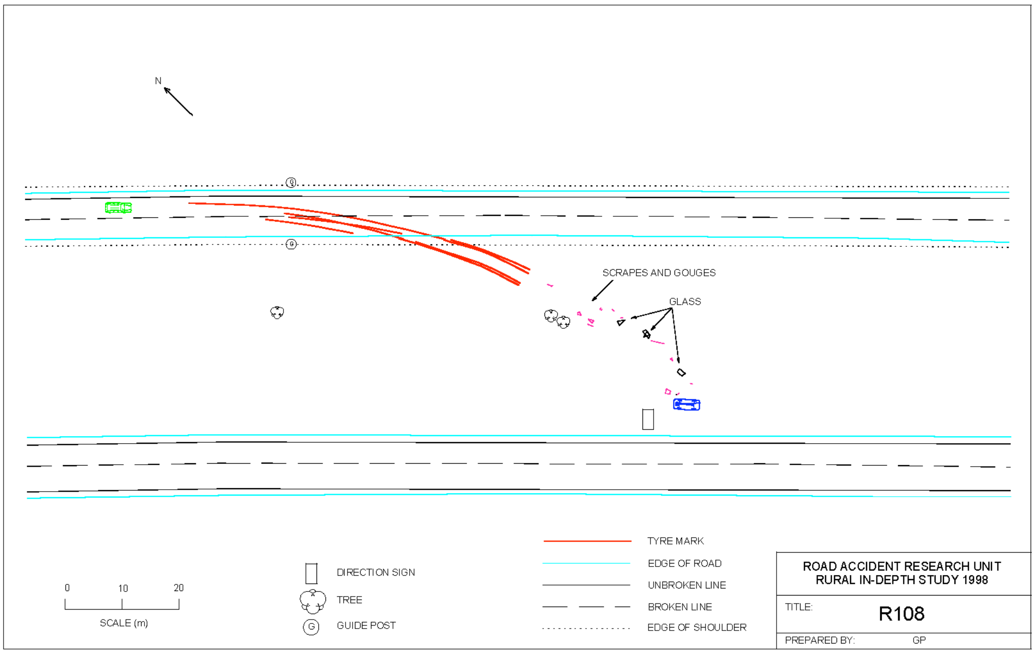


Figure 3.5
Tyre yaw marks from left hand side wheels
Case R108 (see text)

Figure 3.6
Vehicle in final position, viewed from the opposing traffic lanes
Case R108 (see text)

4 Vehicle characteristics and rollover prevention

There is an extensive research literature on rollover crashes (see, for example, Deutermann, 2002 and Eigen, 2003). This section of the report does not attempt to review the whole body of this literature but rather to provide an overview of developments in our understanding of those characteristics of vehicles that are related to rollover prevention. The similarly important matter of the crashworthiness of vehicles in rollovers is not addressed in this report.

4.1 Static rollover stability

Until the early 1990s attention was focussed primarily on the static lateral stability of a vehicle as a measure of the risk of that vehicle rolling over in a turn or emergency evasive manoeuvre. Lateral stability, referred to at that time as the Rollover Stability Factor but now more commonly Static Stability Factor (SSF), was measured as a function of the track of the vehicle in relation to the height of its centre of gravity.

Robertson, at the Insurance Institute for Highway Safety (IIHS) reported that certain models of utility vehicle (now commonly referred to as Sport Utility Vehicles or SUVs) were at particularly high risk of being involved in fatal rollover crashes and that this risk was strongly correlated with the static stability of the vehicle. (Robertson, 1988)

Harwin and Brewer, researchers at the United States National Highway Traffic Safety Administration (NHTSA) also found that there was a close correlation between the vehicle rollover stability factor and the risk of vehicle rollover in a single vehicle accident. Their work identified two SUVs which had a much higher than average risk of involvement in rollover crashes but this was not taken up by the Administration of NHTSA at that time and their reports were not publicly released. The referenced work by these researchers was published by them at a later date. (Harwin and Brewer, 1991) They also found that the rollover stability factor was not as good a predictor when used to estimate the likelihood of rollover per registered vehicle, indicating that other factors needed to be considered.

4.2 Dynamic rollover stability

Dynamic rollover stability is defined in relation to the propensity of a moving vehicle to roll over in a manoeuvring test. This approach to the investigation of rollover stability has been succinctly described by Forkenbrock et al (2003):

> "Thirty years ago, the National Highway Traffic Safety Administration (NHTSA) began studying the use of dynamic maneuvers to evaluate light vehicle rollover resistance. At that time, it was concluded the maneuvers being studied had such major problems, particularly in the area of objectivity and repeatability, that they could not be used by the Government to effectively rate rollover resistance. Today, following much effort, this is no longer the case."

The NHTSA New Car Assessment Program (NCAP) now includes a rollover resistance rating that is still based primarily on the Static Stability Factor but it is adjusted according to the results of a driving manoeuvre that tests whether a vehicle tips up (see: www.safercar.gov). This manoeuvre is referred to as the "fishhook" or Road Edge Recovery manoeuvre which, as its name indicates, is very similar to the motion which results from a driver allowing a vehicle to run off onto the unsealed shoulder and swerve abruptly back onto the road, often then overcorrecting back to the left, as was commonly the case in the rollover crashes reviewed in Section 3 (see Figure 3.3). The "fishhook" manoeuvre involves an abrupt left turn followed immediately by an abrupt right turn. The actual testing is done both to the left and to the right. The steering inputs are controlled remotely, although the vehicle is driven up to that point. Titanium outriggers attached to the vehicle allow the assessment of wheel lift if a vehicle tips up, but prevent it from continuing to roll over.

4.3 Rollover resistance ratings

The United States NCAP rollover resistance rating is primarily based on the Static Stability Factor for the following reason:

> "About 95% of rollovers are tripped - meaning the vehicle struck something low, such as a curb or shallow ditch, causing it to tip over. The Static Stability Factor (SSF) is specifically designed to measure this more common type of rollover and thus plays a significantly larger role in a vehicle's star rating" .... "than the results of the dynamic maneuvering test." <http://www.safercar.gov/Rollover/pages/faqs.htm#howisa>

Several important factors have become apparent, or confirmed, in the testing and other research conducted by NHTSA. The risk of a rollover crash increases with travelling speed (Deutermann, 2002), as indicated here in Tables 2.11 and 3.3 in terms of the speed limit as a surrogate measure of travelling speed. As is generally recognised, SUVs (4WDs) have a higher rate of involvement in rollover crashes. This is also documented in Deutermann (2002) where SUVs are shown to have about three times the rate of involvement in fatal rollover crashes as regular passenger cars per 100,000 vehicles registered. A factor that is less commonly recognised is the importance of passenger loading on rollover propensity.

Subramanian (2003) has compared rollover rates in single vehicle crashes for vehicles with the driver alone compared with the same type of vehicle with a full load of passengers. The risk of rollover is increased by as much as 40 per cent for an SUV, which is clearly of concern, but 15 passenger vans have an increased risk of rollover when fully laden that is more than three times greater than with the driver alone in the vehicle. In the United States, Federal law prohibits the sale of 15-passenger vans for the school-related transport of high school age and younger students, but no such prohibition exists for vehicles to transport college students or other passengers.

(See <http://www.nhtsa.dot.gov/cars/rules/interps/files/17730.drn.htm> for an interpretation of the Federal law.)

4.4 Electronic stability control

Electronic stability control (ESC) uses technology which is an extension of the antilock braking system (ABS) which is fitted to most new cars. (The terminology for ESC varies from one manufacturer to another but the technology is similar.) Additional sensors monitor the steering angle and rotation around the vertical axis of the vehicle. When they detect that the vehicle is not travelling in the direction indicated by the position of the steering wheel the ESC system automatically applies the brake on one or more wheels to help the driver to maintain control over the vehicle.

Evaluations of the effectiveness of ESC in reducing crashes have been reported in the United States recently. The results have been astounding (a term which is rarely justified in a technical report such as this).

The Insurance Institute for Highway Safety reported that cars and SUVs equipped with ESC had 56 per cent fewer fatal single vehicle crashes than the same make and model without ESC. (Insurance Institute for Highway Safety, 2005) The effect was much less for multi-vehicle fatal crashes (17 per cent reduction) but overall there was a 34 per cent reduction in all fatal crashes. When all crashes, fatal and nonfatal, were studied it was found that there was a 41 per cent reduction in single vehicle crashes and a 7 per cent reduction in all crashes.

NHTSA, in a separate evaluation (Dang, 2004), reported that single vehicle crashes were reduced by 35 per cent for passenger cars and 67 per cent for SUVs. The corresponding percentages for fatal single vehicle crashes were 30 per cent and 63 per cent respectively.

As noted in Section 3.17, in every case in our in-depth study in which a car rolled in a single vehicle crash it yawed out of control before rolling over. It is clear that the introduction of electronic stability control has great potential to achieve similar savings from crash reduction in Australia as has been the case in the United States.

4.5 Assessment of rollover resistance and electronic stability control

As discussed above, the assessment of a vehicle's resistance to rollover involves a combination of two tests, one very simple (static stability) and one complex (dynamic stability). The assessment of the effectiveness of a system of electronic stability control is clearly in the complex category. The issues involved and the approaches being considered to these assessments worldwide have been reviewed by Paine (2005). He recommends that:

> "Australian authorities monitor overseas developments concerning the assessment of ESC. At this stage none of the surveyed overseas projects have produced a *performance-based* test protocol and/or rating system that is fully suitable for use in a consumer program (or regulation)."

5 Conclusions

Rollovers that occur following a collision with another vehicle have the potential to add significantly to the severity of the injuries sustained by the occupants of those vehicles but there are even greater reasons to be concerned about single vehicle rollovers.

The risk of a casualty crash being a single vehicle rollover increases markedly at higher travelling speeds, as indicated by the speed limit of the road on which the crash occurs. This adds strong support to the case for reductions in the higher speed limits in rural areas.

Eighty per cent of the single car rollover crashes in the in-depth study sample were initiated by the car running at least partially onto the left unsealed shoulder. Countermeasures such as audio-tactile edge lining and sealing the shoulder could be expected to reduce the frequency of out of lane excursions and the loss of control in those excursions that do occur.

The important role of seat belt wearing in protection against serious or fatal injury was confirmed yet again in the rollover crashes investigated in the in-depth study.

The adverse effect on rollover resistance of passenger and goods loading on 4WD vehicles and passenger vans, while not identified in the data analysed in this study, has been publicised widely by the United States National Highway Traffic Safety Administration and is deserving of serious consideration in Australia.

Experience with electronic stability control (ESC) in the United States shows that it is by far the most effective vehicle-based crash preventive measure ever developed, particularly with respect to single vehicle crashes, of which rollovers are a large part. It is recommended that consideration be given to allocating a substantial proportion of road safety publicity budgets to publicising the safety benefits of electronic stability control, as has been done by the Swedish Road Administration (Personal communication, Claes Tingvall, October 2005) to encourage both the provision of ESC on new vehicles and the purchase of vehicles so equipped.

As there is still no consensus about ways to assess dynamic rollover stability and the effectiveness of various electronic stability control systems, it is suggested that Australian authorities continue to monitor overseas developments before considering the introduction of any regulatory measures.

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