Characteristics of Rollover Crashes

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This paper was originally presented at the Australasian Road Safety Research, Policing and Education Conference held at Surfers Paradise, Queensland, 25-27 October 2006.

Abstract

This paper analyses data from an in-depth study of rural crashes, supplemented by some data from police reports on crashes, to examine the characteristics of rollover crashes in South Australia. The risk of a crash being a single vehicle rollover increases markedly at higher travelling speeds and eighty per cent of them were initiated by the vehicle running at least partially onto the left unsealed shoulder. Road and traffic related countermeasures such as audio-tactile edge lining and sealed shoulders are noted, as is the potential to reduce the risk of a crash being a single vehicle rollover by reducing rural speed limits. The paper concludes with a brief discussion of the design of vehicles in relation to rollover crashes, including the benefits of electronic stability control.

Method

A series of 236 rural road crashes to which an ambulance was called within 100 km of Adelaide was investigated by the Road Accident Research Unit (now the Centre for Automotive Safety Research, CASR) between March 1998 and February 2000. Unit personnel attempted, usually successfully, 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, initially at the scene in some cases and later in follow up interviews. In some fatal cases, where the vehicle positions had been marked by the Police Major Crash Investigation Unit, the CASR investigating team examined the crash scene within 24 hours. This had the effect of increasing the proportion 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.

Some comparisons are made with data on all reported crashes in South Australia from the Traffic Accident Reporting System (TARS). These comparisons are influenced by the inclusion of crashes in the metropolitan area of Adelaide in the State-wide TARS data and by differences due to the study area including most of the hill country in the State.

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 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 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

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 2). The percentage on straight roads was slightly higher in the TARS cases (57%) which may be due to chance variation but also to the topography of the in-depth study area which, as noted above, 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 paper.

Table 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 per cent of these single vehicle rollover crashes occurred on roads having a speed limit of at least 100 km/h (Table 3). However, 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 per cent for single vehicle rollover crashes. 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 State-wide TARS data, to the extent that 30 per cent of all crashes on 110 km/h speed limit roads are single vehicle rollovers, compared with less than 20 per cent on 100 km/h roads (Table 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 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:** Crashes resulting in a fatality or injury requiring at least treatment at hospital in South Australia 1999-2003

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 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 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 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 5 and 6). Conversely, cars were much less likely to be the vehicle which rolled following a collision (45.5%).

Table 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 6). The relative involvement of cars compared to other vehicles (mostly 4WDs) differed markedly however depending on whether or not the vehicle struck a fixed object, usually a tree, before rolling over. In the cases involving no prior impact, 42.1 per cent of the vehicles were cars whereas the corresponding percentage for cars in rollover crashes with a prior impact was 83.3 per cent (Tables 7 and 8, 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 above, it is likely that a rollover would still have occurred in many of these cases. The evidence for this is presented later in this paper.

The numbers of cases involving 4WD vehicles in Tables 7 and 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 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 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 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	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 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.

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Table 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 See note to Table 3; 2 Two towing a trailer; 3 One towing a trailer; 4 Included above

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 per cent of all of these 43 drivers, slightly more than the 14.4 per cent 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.

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 per cent respectively (Table 10).

Table 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

Table 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

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 11). However, a slightly larger difference was observed in the TARS data and it was statistically significant, as would be expected with the much larger number of cases.

Injury severity

Injury severity is expressed here in terms of the level of treatment required or, for fatal cases, the outcome. The distribution of the maximum injury severity in each of these single vehicle rollover crashes is shown in Table 12.

Table 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 earlier in this paper.

The comparison of the distribution of injury severities between single vehicle rollover crashes and other crashes shown in Table 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 per cent of the occupants in single vehicle rollover crashes were in that category compared with 38 per cent 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 resulting in a fatal injury was within the bounds of chance variation, and partially due to the method of inclusion of such cases.

Table 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.

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 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 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 15).

Table 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 16).

Table 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

Vehicle movements preceding rollover

Most of the cars involved in single vehicle rollovers in this sample of crashes were travelling on a straight road (Table 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 17 Cars in single vehicle rollover casualty crashes by road alignment and initial and final off road excursion

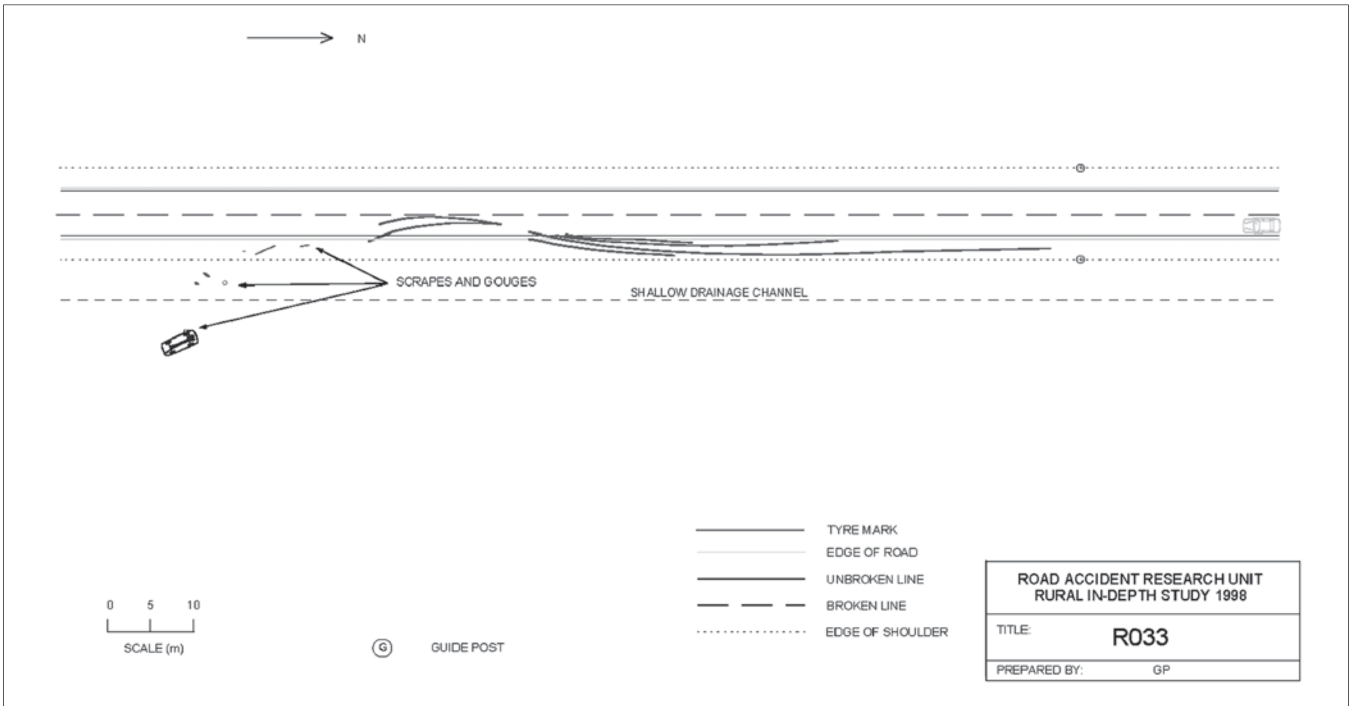
	Initial off road excursion on:		Final off road excursion on:	
Road alignment	Left	Right	Left	Right
Straight	12 (4)[1]	2 (1)	5	4
Right curve	6 (2)	2 (2)	3	1
Left curve	3 (2)	1	1	1
Total[2]	21 (8)	5 (3)	9	6

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. The typical 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 when the driver swerved back to the right and then overcorrected to the left, as shown in the site diagram of one such crash. (Figure 1)

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 17).

Figure 1 Site diagram showing tyre marks from initial off road excursion and overcorrection back to the left. Case R033



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 nine cases occurred on curves whereas less than half of the car crashes were initiated on curves (Table 18).

Table 18 4WDs in single vehicle rollover casualty crashes by road alignment and initial and final off road excursion

	Initial off road excursion on:		Final off road excursion on:	
Road alignment	**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

Vehicle Characteristics and Rollover Prevention

Rollover resistance ratings

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, commonly referred to as the Static Stability Factor (SSF), is measured as a function of the track of the vehicle in relation to the height of its centre of gravity.

The United States New Car Assessment Program (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."

The "dynamic maneuvering test" (see: www.safercar.gov) measures whether a vehicle tips up in a "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 here.

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.

The Insurance Institute for Highway Safety has reported that cars and SUVs equipped with ESC had 77 per cent and 80 per cent respectively fewer fatal single vehicle rollover crashes than the same make and model without ESC. (IIHS, 2006)

Discussion

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.

As already noted, in every case in this 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.

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 (Tingvall, 2005) to encourage both the provision of ESC on new vehicles and the purchase of vehicles so equipped.

Acknowledgements

The assistance of Matthew Baldock, Tori Lindsay and Andrew van den Berg is gratefully acknowledged.

This study was funded by the South Australian Motor Accident Commission (MAC) through a Project Grant to CASR. The MAC Project Manager was Ross McColl.

The Centre for Automotive Safety Research receives core funding from both MAC and the South Australian Department of Transport, Energy and Infrastructure.

The views expressed in this report are those of the authors and do not necessarily represent those of the University of Adelaide or the sponsoring organisations.

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