Effectiveness of ABS and Vehicle Stability Control Systems

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Title

Evaluation of Anti-lock Braking Systems Effectiveness

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Abstract

A literature review of advanced technology braking systems and vehicle stability control systems available or under development around the world was undertaken. Literature on the range of devices available as well as their likely effectiveness in preventing crashes and injuries was sought from a range of scientific and engineering sources for the review. In addition, an analysis was also performed on local data sources to assess potential safety benefits in Australia. The findings from this review were somewhat inconclusive. Some evidence suggested that vehicles equipped with an Anti-lock Braking System (ABS) were involved in fewer crashes with opposing, adjacent or same direction vehicles compared to non-ABS fitted cars but were over-involved in run-off-the-road crashes. The analyses performed on local data suggested that ABS may have had some benefit in reducing injury severity to vehicle occupants in some specific models but these findings were rather weak and inconsistent. Preliminary evidence suggested that Electronic Stability Programs (ESP), currently gaining popularity in new vehicles, are having a very positive influence on safety with claims of reductions in crashes and injuries by up to 35%. More comprehensive data that allow the effectiveness of ESP in improving safety in all surface conditions (i.e. wet, dry and icy) and for all types of crash configuration are required. While it is always difficult to evaluate the effectiveness of devices that prevent crashes using crash data, the study makes a number of recommendations on how additional analyses might be undertaken to statistically confirm the findings presented here.

Key Words

ABS, anti-lock brakes, anti-lock braking system, emergency braking, active safety, primary safety, advanced braking system, crash avoidance, vehicle safety

Disclaimer

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EXECUTIVE SUMMARY

Since their introduction, Anti-lock Braking Systems (ABS) have been acclaimed as providing significant improvement in braking and hence crash and injury reduction on our roads. Yet, the real-world crash evidence to support these claims is thin and equivocal.

In addition, there are a number of different Anti-lock Braking Systems in modern vehicles, including single, three-way and four-way sensing systems. These systems vary in terms of their level of sophistication and are therefore also likely to vary in terms of their expected performance. Yet, rarely have effectiveness studies attempted to parcel out their relative differences, other than for a single vehicle model.

The Monash University Accident Research Centre conducted a study for RACV Limited in Victoria to assess the effectiveness of ABS on crash and injury risk. In addition, the likely benefits of other advanced technology braking systems such as Electronic Stability Programs (ESP) or Vehicle Stability Control (VSC) systems were also evaluated. Given the current paucity of data available, an overall analysis of the likely effectiveness of these systems in Australia was attempted to see if there were any signs of local differences compared with overseas studies.

Studies on the Effectiveness of ABS

A number of studies examining the effectiveness of ABS in real-world crashes have been conducted in the US. Claims of effectiveness vary up to 48% depending on vehicle and crash type and outcome severity. Some studies suggested that ABS decreased the rate of rear-end, head-on and pedestrian crashes, while increasing the likelihood of single-vehicle and rollover crashes. The benefits were also less impressive among non-fatal crashes.

Given the superior braking performance of ABS over standard brakes observed in braking tests, some have argued that the lack of reliable findings in the field data might lie in behavioural responses to these systems.

Explanations vary from driver adaptation, unsafe practices (e.g. excessive speeding), insufficient headway, and poor steering behaviour. Others have argued that inexperience with ABS systems can lead to drivers failing to use the system as it was designed (e.g. by taking their foot off the brake following the onset of the system). It is likely that at least some of these driver responses may help to explain these findings. However, they are unlikely to be the sole explanation.

While ABS has generally been applied to cars, there are also examples of its application to trucks and motorcycles. For light trucks and vans, an increased involvement of ABS fitted vehicles was observed in side impacts and rollover multi-vehicle collisions, while a reduction in crash involvement of these types of crashes was found among single-vehicle impacts. Rear-wheel ABS fitment had an added advantage compared to all-wheel ABS vehicles.

It has been argued that ABS is even more important for motorcycles than cars given their high crash involvement, yet the crash data for these vehicles with ABS is sparse. This may reflect the current low fitment rates of ABS to motorcycles. Furthermore, there are suggestions of over-confidence among motorcycle riders with machines fitted with ABS.

Effectiveness of Electronic Stability Programs (ESP)

ESP is a closed-loop system that prevents or limits lateral instability. It aims to prevent the vehicle spinning out of a turn when cornering too fast by redistributing the braking performance across all wheels.

To date, evidence of the effectiveness ESP or Vehicle Stability Control (VSC), as it is sometimes called, is inconclusive but promising. Claims of an overall improvement of approximately 20% have been published for ESP-fitted vehicles over non-ESP-fitted vehicles and the effectiveness is even greater on wet and icy roads and for single and multi-vehicle crashes and casualties. More comprehensive analyses are required as these safety systems increasingly become standard fittings in modern vehicles.

Australian Analysis

To supplement these overseas findings, an analysis of ABS and non-ABS cars was conducted using crash data from Australia. ABS details of crashed vehicles were obtained from 12 local vehicle suppliers and used to compare with other non-ABS crashed cars. Results were restricted to driver-effects only and speed zone and age of driver were controlled for using regression-modelling techniques.

Although none of the results achieved statistical significance, nevertheless, there were trends consistent with some of the overseas studies. Four of seven models assessed showed a reduction in injury severity for ABS-fitted vehicles. However, the risk of injury given crash involvement was seen to rise among seven of the eleven models, suggesting some form of behavioural adaptation to these systems. Further analysis is desirable when more data are available locally or by using other larger international databases.

Conclusions

This study set out to examine the effectiveness of ABS in reducing vehicle occupant injury risk and injury severity from the literature as well as from a local analysis of real crash outcomes. The overriding conclusion from the evidence examined is that ABS seems to be effective in reducing some types of crashes (eg; multi-vehicle, rear-end and head-on crashes) but can lead to increases in others (eg; single-vehicle and rollover collisions). Reductions in crash severity have been reported but dampened to some degree by increases in crash risk.

It is difficult to establish the full effect of ABS from crash data as this cannot take account of the number of crashes prevented, an important aspect of ABS effectiveness. There were some suggestions that the fitment of ABS was associated with changes in driver behaviour from excessive speeding, allowing insufficient headway, poor steering behaviour and inexperience with the system.

Vehicle stability control systems, such as ESP or VSC, may also enhance the braking performance of ABS-equipped vehicles and should therefore be monitored further as their use becomes more widespread.

Further analysis examining the absolute risk of crash involvement using induced exposure methods and larger databases would be helpful in understanding ABS effectiveness more fully.

1. Aims & Background

1.1. Aims

The aim of this report is to assess the effect of Anti-Lock Brake Systems (ABS) and Vehicle Stability Control Systems (ESP and VSC) on vehicle occupant injury risk and injury severity both through the analysis of real crash outcomes described in mass crash data and a review of current literature. In evaluating the safety performance of ABS it is necessary to consider factors such as crash configuration, involvement, environmental conditions and injury risk. Furthermore, it is important to rationalise any difference in crash distribution between ABS-equipped and non-ABS equipped vehicles, with respect to the aforementioned crash characteristics.

1.2. Background

Since its introduction, ABS has been acclaimed as providing significant improvement to overall vehicle safety. By prevention of wheel lock-up, ABS enables the driver to maintain steering control during emergency braking and can also reduce stopping distances on some slippery surfaces (note: ABS increases distances on gravel). Vehicle manufacturers have undertaken extensive marketing campaigns to promote the safety of their vehicles on the basis that they are equipped with ABS. Within the community there is a general perception that vehicles fitted with ABS are safer than those without. In a US poll, consumers ranked ABS as second only to seat belts when buying a new car (www.adtsea.iup.edu).

The principal reason for equipping passenger cars and light trucks with ABS is to increase safety (Forkenbrock, et al, 1998). Track experience and data have shown the benefits of ABS in reducing stopping distances and maintaining steering control. Such results, and not real-world crash data, have driven the assumption that ABS has a positive net safety benefit. This leads to the obvious question: How effective is ABS in reducing injuries in the real-world? It can be shown that the distribution of crash types and severity for ABS-fitted vehicles is significantly different to that of non-ABS fitted vehicles. It is therefore, very important to understand the real-world advantages and disadvantages of ABS.

ABS is by no means a new innovation and its development and acceptance has occurred over a number of decades. The first ABS was the 1952 Dunlop Maxaret, which was used on aircraft landing systems (Veloso and Fixson, 2001). In 1978, Robert Bosch GmbH introduced the modern anti-lock braking system for passenger vehicles (Marshek et al, 2002). By the 1990's, ABS was a common option on many vehicles, and currently ABS is a standard or, at least an optional feature on nearly all new vehicles. Figures from the US estimated that 95% of new vehicles would be fitted with ABS in 2003 (Veloso and Fixon, 2001). In line with its objective of improving pedestrian safety, the European Automobile Manufacturers Association (ACEA), in discussions with the EU Commission, has committed to equipping all new vehicles with ABS in 2003. No such arrangement or regulation exists in Australia. However, ABS is becoming a common feature on new Australian vehicles

Electronics is expected to play a major role in accident warning and avoidance technologies in the future (Prasad, 2000). Following the increased level of adoption of ABS, recent times have seen the rate of development of active safety systems increase sharply. Many of these safety systems extend the capabilities of ABS, by taking control of vehicle braking and other inputs away from the driver and applying alternative ("safer") inputs based on predetermined algorithms. Braking based systems include, non-exhaustively, *traction control*, *electronic stability control (ESP)/vehicle stability control systems (VCS)*, *emergency brake assistance* and *intelligent braking systems*. Currently there are limited data surrounding the real-world effectiveness of these new technologies, and the impact of these active safety devices will not be realised until the products become more integrated into the vehicle population.

1.3. Report Layout

This report will be presented in two main sections, firstly a review of current literature (Chapter 2), and secondly an analysis of the effectiveness of ABS based on Australian data (Chapter 3-7).

The emphasis of the literature review is on the effectiveness of ABS and ESP and VSC in passenger vehicles. The study considers the crash types and configurations in which ABS-fitted vehicles are involved, in comparison to crash distributions of non-ABS vehicles. Furthermore, track test data of ABS vehicles and literature discussing the rationale for any differences in the crash distribution of ABS and non-ABS fitted vehicles are presented. Available ABS light truck and motorcycle literature is also presented, as is literature evaluating the effectiveness of vehicle stability control systems and other active braking systems.

The statistical analysis examines the effectiveness of enhanced braking systems in terms of both primary and secondary safety. Primary safety is assessed by reference to the distribution of occupant injury risk and severity and the absolute risk of crash involvement for ABS and non-ABS equipped vehicles. In contrast, the secondary safety effects of these systems are evaluated using poisson and logistic regression models that examine the effectiveness of such systems at the individual vehicle model level and control for other factors that may affect the safety outcome.

2. Literature Review

The sources of literature that have been accessed for this review include safety, medical and engineering journals. All literature presented has been obtained from overseas data, and this fact should be borne in mind when considering these findings in the Australian context.

2.1. Anti-Lock Brake Systems

Antilock braking systems are closed-loop control devices that prevent wheel lock-up during braking and as a result vehicle stability and steering is maintained. System components include: a wheel-speed sensor, a hydraulic modulator and an Electronic Control Unit (ECU) for signal processing and control and triggering of the signal lamp and of the actuators in the hydraulic modulator (Bauer, et al, 2000). ABS functions by detecting the onset of wheel lock-up, due to a high braking force, and then limiting the braking pressure to prevent wheel lock-up. The ECU recognises the wheel lock-up as a sharp increase in wheel deceleration. Braking force is reapplied until the onset of wheel lock-up is again detected at which point it again reduces the brake force in a closed loop process. The cyclic application and reduction of braking force ensures that the brakes operate near their most efficient point and maintains steering control. This cyclic application is also responsible for the pulsating that a driver feels through the brake pedal when the system is activated.

When the driver applies the brake, brake slip increases and at the point of maximum friction between tyre and road surface the limit between the stable and unstable range is reached. At this point any increase in brake pressure will not increase the stopping force; as further brake pressure is applied the friction reduces and the wheel tends towards skidding. On a wet or icy surface the degradation in friction will be large as the wheels lock-up, whereas on a surface such as dry bitumen the degradation in braking force will be relatively small. The practical result is that vehicle stopping distances with locked wheels are similar to those where ABS is operating on dry bitumen, and much larger on wet surfaces.

The advantage of ABS that is most publicised is that it gives the driver the ability to steer during emergency braking. In a vehicle with a conventional braking system as the wheels tend towards lock-up, the lateral friction that enables steering reduces greatly and approaches zero when fully locked. By preventing wheel lock-up lateral friction between the road surface and the tyre is maintained at a high level, as a result of which vehicle steering control in ABS fitted vehicles is maintained during emergency braking.

2.1.1. Types of ABS

There are a number of different Anti-lock Brake Systems. The first and most advanced is a four-channel, four-sensor system, which has a speed sensor on each wheel and separate valves to control brake pressure to each wheel. Another is the three-sensor, three-valve system, which has a speed sensor and controlling valve for each of the front wheels and a single channel and valve to prevent lock-up of both rear wheels. The most basic system is the single-channel, single-sensor system that operates on both rear wheels. This system is most commonly fitted to trucks or pick-up trucks.

2.2. Crash Configurations & Types

2.2.1. Single versus Multi-vehicle Crashes

The effect of ABS on crash distributions that is most pronounced is in the relative occurrence of single and multi-vehicle crashes. Real-life data consistently demonstrate that the risk of a single-vehicle crash in an ABS vehicle is greater than in a non-ABS vehicle. The converse occurs in multiple vehicle crashes. This evidence, coupled with the fact that single-vehicle impact severity is often very high, may indicate that ABS does not necessarily increase occupant safety. An explanation for this “anomaly” is discussed below in section 2.3.2. The findings of various authors are presented.

Kullgren et al. (1994) found in a Swedish study that cars with ABS had more single-vehicle crashes where one vehicle crossed over to the wrong side of the road. This proportion was higher for all road surfaces. They also found that cars with ABS travelling on roads with lower friction were more likely to be struck from behind but that these vehicles were less often the striking vehicles in rear impacts. On dry surfaces this difference was not apparent.

Kahane (1994) found that fatal run-off-road crashes in the US were up by 28% for ABS-fitted vehicles (17% for wet roads, 29% dry roads) and non-fatal run-off-road crashes increased by 19%.

Evans and Gerrish (1996) studied seven GM vehicle models in the US where ABS was unavailable during 1991 and fitted as standard equipment in 1992. They found that on wet roads ABS reduced the risk of a vehicle crashing into a lead vehicle compared to the risk of being struck from behind by 48% (+/- 6%). ABS reduced the risk of crashing into a lead vehicle by 32% (+/- 8%). However, it increased the risk of being struck from behind by 30% (+/-14%). Conversely, on dry roads ABS-equipped vehicles were more likely to crash into the rear of vehicles, with an estimated increase of 23% (+/-15%). This result was unexpected and suggested an increase in risk taking behaviour by ABS drivers.

Hertz et al. (1996) found a significant reduction in non-fatal frontal multi-vehicle crashes for ABS-fitted vehicles but increases in non-fatal frontal and side impacts with stationary vehicles and fixed objects in a study conducted in the US. Significant increases in single-vehicle fatalities were also associated with ABS fitment.

Farmer et al. (1997) investigated the risk of fatal crash occurrence in the US. The vehicles included in the study were selected as models, in which ABS was not available in one model year but a standard feature in one of the following two model years. Fourteen GM vehicle series that switched to the same standard ABS in 1992 were analysed. The results showed significant increases in single-vehicle crashes (17%), particularly on dry surfaces (21%) whereas the risk of fatal multi-vehicle crashes involving an ABS vehicle was reduced by 5%. Non-GM vehicles were also considered, and they exhibited very similar crash distributions.

Evans (1998) found in a US study that, on wet roads, ABS reduces the risk of crashing into a lead vehicle by 32%, and increases the risk of being struck behind by 30%.

Hertz et al. (1998) updated the crash data from their previous work (Hertz et al., 1996) and found that the significant reduction in non-fatal frontal multi-vehicle crashes remained. However, differences in side impacts and run-off-road crash risk on unfavourable surfaces (i.e. wet, icy or snow-covered) were not significant, whereas previously they had been associated with an increased risk.

Farmer (2001) found a 10% increase in the risk of any fatality in single-vehicle crashes associated with ABS, and a corresponding 7% reduction in multi-vehicle crashes in a study in the US.

2.2.2. Rollovers

Rollover crashes are frequently the result of a single-vehicle run-off-road type incident. An increase in single-vehicle run-off road type crashes, as shown in the previous section, should be accompanied by an increase in rollover crashes. Data analysis completed in the literature demonstrates the existence of such an increase in rollover crash risk, and as a result of ABS fitment. The findings of various authors as to the effect of ABS-fitment on the risk of a rollover crash are presented below:

- Evans (1995) found a 44± 22% increase in rollover crash risk.
- Hertz et al. (1996) found a 60% increase in risk of a fatal rollover, and a 24% increase in risk of all rollover crashes.
- Farmer et al (1997) found a 37% increase in the risk of fatal rollover crashes, and a 29% increase in fatal single-vehicle rollover crashes.
- Hertz et al. (1998) found a 51% increase in the risk of a fatal rollover on unfavourable surfaces (i.e. wet, icy or snow-covered), and a 17% decrease in risk of rollover crash occurrence on favourable surfaces (i.e. dry and free of debris).
- Evans (1998) found a 39±16% increase in rollover risk compared to the risk of a non-rollover crash.
- Farmer (2001) updated fatality data and found that the increase in the risk of rollover was 3%, and the increase in single-vehicle rollovers was 6%, a significant change from earlier fatal rollover results.

2.2.3. Pedestrian Impacts

More emphasis is now being placed upon vehicle manufacturers to protect pedestrians. This includes both collision avoidance and severity-mitigation technology. Data has consistently demonstrated that ABS greatly reduces the occurrence of severe pedestrian collisions. The findings of various authors as to the effect of ABS-fitment on the risk of pedestrian impacts are presented below:

- Kahane (1994) found a 27% reduction in fatal pedestrian impacts, and a 3% increase in the number of these impacts.
- Evans (1995) found a 34±15% lower risk of pedestrian crashes (assuming no change for non-pedestrian crashes).
- Data examined more recently by Evans (1998) showed a 22±11% decrease in pedestrian crashes compared with the risk of a non-pedestrian crashes.
- Farmer et al. (1997) found a 1% reduction in the risk of fatal pedestrian impacts. In wet conditions there was a 10% reduction in risk but in dry conditions there was increased risk.
- Farmer (2001) found a 5% reduction in the risk of fatal pedestrian impacts.

2.2.4. Surface Conditions

The effect of ABS in reducing crash occurrence is most pronounced in wet weather conditions. Most ABS studies have found significant differences in the effectiveness of ABS in reducing collisions in wet and dry conditions:

- Kullgren et al (1994) found that cars fitted with ABS travelling on roads with lower friction were more often struck from behind and that these vehicles were less often the striking vehicles in rear impacts. On dry surfaces this difference was not apparent.
- Kahane (1994) found that with the introduction of ABS, involvement in multi-vehicle crashes resulting in fatalities on wet roads were reduced by 24%, and non-fatal crashes by 14%.
- Evans (1995) studied the relative crash risk of vehicles equipped with ABS in certain conditions. The study used seven GM vehicles fitted with ABS as standard equipment in 1992, and 1991 models without ABS. His conclusions as to the relationship between ABS and crash risk were as follows and were based on the assumptions in parentheses:
  - 13±4% lower crash risk on wet roads (assuming equal crash risk on dry roads).
  - 13±5% lower crash risk when raining (assuming equal crash risk when weather conditions are clear).

- Padmanaban and Lau (1996) found in US police reported data a 16-17% reduction in crash occurrences with ABS on wet roads, and a 6-9% reduction in the crash occurrence on dry roads.
- Evans (1997) found that, when driving on wet roads, ABS reduces the risk of a vehicle crashing into a lead vehicle compared to its risk of being struck in the rear by 48%. Assuming that side impact crash exposure is not dependant on ABS fitment and can be used as a control, then on wet roads ABS reduces the risk of crashing into a lead vehicle by 32%; but increases the risk of being struck from behind by 30%.
- Farmer et al. (1997) found a 1% reduction in the risk of fatal pedestrian impacts. However, the reduction in risk in wet conditions was significantly greater (10%). There was also a slight reduction in rollover crashes in wet conditions associated with ABS. However, a large increase in fatal rollovers was present in dry conditions.
- Evans (1998) found a 10±3% relative lower crash risk on wet roads compared to the corresponding risk on dry roads.
- Hertz (1998) found significant differences in the effects of ABS fitment in different conditions. ABS reduced the risk of pedestrian crashes by 30% in unfavourable conditions (i.e. wet, icy or snow-covered) and only 10% in favourable conditions (i.e. dry and free of debris). Frontal crashes were 42% less likely to occur with ABS in unfavourable conditions and 18% less likely in favourable conditions. The conditions did not have a significant effect on the occurrence of fatal side impacts. In favourable conditions, a 61% increased risk due to ABS was present, and similarly in unfavourable conditions this risk was 69%. The results showed that the existence of unfavourable conditions tended to magnify the extent of the change in crash distribution. However, the direction of the change, i.e. whether ABS was a benefit or not, was generally the same for both conditions.

2.3. Overall Effectiveness

2.3.1. Crash Effects

In an overview of the NHTSA (National Highway Traffic Safety Administration) ABS research program, Garrot and Mazzae (1999) describe the typical findings of ABS studies. ABS is associated with:

1. a statistically significant **decrease** in multi-vehicle crashes.
2. a statistically significant **decrease** in fatal pedestrian strikes.
3. a statistically significant **increase** in single-vehicle road departure crashes.

The safety disbenefit from the third finding virtually cancels the safety benefits from the first two findings.

Early data showed little overall effect of ABS, however it served to highlight differences in crash distributions. Evans (1995) found only approximately 3% reduction in overall crash risk in vehicles fitted with ABS. Kahane (1994) compared the crash rates between vehicles with and without ABS. The study showed that vehicles with ABS were involved in fewer crashes with other vehicles and pedestrians than those without ABS. However, ABS-fitted vehicles were involved in a larger number of off-road crashes, meaning that the total number of crashes did not differ significantly between ABS and non-ABS vehicles. Kullgren (1994) found that there was a large and consistent difference between the ratio of cars with and without ABS involved in crashes depending on the road condition and whether the car was struck from behind. The most significant outcome from the studies conducted by Kahane (1994) and Kullgren (1994) was that they established a clear difference in the crash patterns of vehicles fitted with ABS and those not fitted with the system.

Padmanaban and Lau (1996) used a matched-pair methodology to collect US police reported data. The matched-pairs consisted of vehicles in consecutive model years; the last model year for which ABS was not fitted to the vehicle and the following year for which ABS was fitted as standard. Vehicles for which ABS was an option were not included in the study. The data from over 60000 crashes showed a 9-11% reduction in overall crash rates, and a 7-16% reduction in injury rates in all road conditions. However, there was no significant difference in the fatality rates of ABS fitted and non-ABS fitted vehicles. The results suggested a significant safety benefit from ABS fitment.

Hertz et al. (1996) analysed the crash experience of passenger vehicles. They found a significant reduction in non-fatal frontal multi-vehicle impacts associated with the presence of ABS. However, significant increases in non-fatal frontal and side impacts with parked vehicles or fixed objects were also associated with the presence of ABS. The balance of the data, increased crash rate for specific crash types and reduced rates for other types, indicated that there was little or no net crash reduction associated with ABS.

Farmer et al. (1997) compared fatal crash rates of passenger cars and vans for the last year of a model where ABS was unavailable and the first model year where ABS was fitted as standard. The overall fatal crash rates were similar for both model years. However, ABS-fitted vehicles were significantly more likely to be involved in crashes fatal to their own occupants.

Farmer (2001) updated fatal crash data and presented important findings. The data showed that the risk of being involved in a crash differed depending upon the age of the vehicle. The study involved GM ABS-fitted vehicles (model year 1992) and GM non-ABS-fitted vehicles (model year 1991). The data were divided into three-year blocks: 1993-95 and 1996-1998. The data showed an attenuation of crash risk in ABS vehicles as they aged. The results are summarized in Table 2.1.

An attenuation in the risks associated with ABS fitment as the vehicle ages is apparent in these results. The author suggests that this may be as a result of drivers becoming more familiar with ABS and better understanding correct braking with the system.

The fatality risk for an occupant of an ABS fitted vehicle is 11% higher than that of an occupant of non-ABS-fitted vehicle (Farmer, 2001). However, the risk of an ABS-fitted vehicle being involved in a crash fatal to a person not in the case vehicle (ABS-vehicle) is 17% lower than the risk in a non-ABS-fitted vehicle. This is representative of the change in crash distribution caused by ABS. The occurrence of more single-vehicle crashes and the reduction in multiple vehicle and pedestrian

Table 2.1 **Crash involvement with and without ABS resulting in a fatality (Farmer, 2001).**

Crash Type	Data years	Change in risk with ABS (%)
All Crashes	1993-95	+3
Multi-vehicle	1993-95	-6
Single-vehicle	1993-95	+18
All Crashes	1995-98	-4
Multi-vehicle	1995-98	-8
Single-vehicle	1995-98	+4
All Crashes	1993-98	-1
Multi-vehicle	1993-98	-7
Single-vehicle	1993-98	+10?

impacts involving ABS fitted vehicles means that ABS reduces the risk to road-users outside the ABS vehicle, but not necessarily to the occupants of the vehicle to which it is fitted.

Broughton and Baughan (2002) assessed the effectiveness of ABS in Great Britain. A postal survey was conducted regarding crash occurrence and driver knowledge of ABS. They found a slight decrease (3%) in the crash risk associated with the presence of ABS. However, due to the low number of crashes, the confidence level of this result was low. Other relevant results were decreases in risk of crashes of men under 55, and increases in crash occurrence for men over 55 and all women. The authors' reason for the increases in crashes by men over 55 and all women may indicate these groups' lack of knowledge as a reason for ABS not achieving the reduction in crashes that was expected.

The majority of the literature suggests that the overall crash effectiveness of ABS is limited or non-existent. In terms of the risk to drivers or occupants of a vehicle the majority of the literature found ABS to be a safety disbenefit. Alternatively, as a measure for reducing the risk to pedestrians and other road users, ABS is beneficial. The increase in risk to occupants of ABS-fitted vehicles balanced with a decreased risk to other road users has little overall influence on safety, other than to change crash distributions. Due to saturation of the vehicle fleet with ABS-fitment, analysis of its effectiveness is becoming more difficult. Despite this, it is important that analyses of ABS vehicle crash data continue as most available data concern older vehicles, and may have been influenced by low levels of understanding of ABS by drivers.

2.3.2. Rationale for Difference Between Test and Real-world Data

It has been indicated that the effect of ABS can increase the severity and occurrence of some crash configurations. It has also been established in track tests that ABS can greatly improve braking performance, particularly in adverse conditions. Then, what remains to be justified is the discrepancy between real-life results and those expected based on track data. Explanations fall into two categories, either based on driver behaviour adaptation, or driver collision avoidance behaviour.

Table 2.2 **Multiple source crash exposure (%) estimates of ABS effectiveness in different crash configurations.**

	All crashes		Rollover		Pedestrian		Run-off-road		Multi-vehicle	
Author	**Fatal**	**All**	**Fatal**	**All**	**Fatal**	**All**	**Fatal**	**All**	**Fatal**	**All**
Kahane	-2	-3	+40	+49	-27	+3				0
Evans (1995)				+44		-34				
Hertz et al (1996)			+60	+24		+3		+15	-1* -35**	-9* -35*
Padmanaban and Lau (1996)		-9.5	0	+11						
Farmer et al (1997)	+16		+63			-1			+7	
Evans (1998)				+39		-22				
Hertz et al (1998)			+40 +51* -14**	-17* +16**	+10* -38**	-10* -30**			+5* -40*	-18* -42**
Farmer (2000)	-1		+3		-5				-7	

**data for favourable (dry) conditions*
***data for unfavourable (wet, slippery) conditions*

Behavioural Adaptation

Evans (1995) suggested that ABS may be associated with a small change in driver behaviour, which increases crash risk. Yamamoto and Kimura (1996) analysed human behaviour in an attempt to determine the cause of increased rollover crashes involving ABS-equipped vehicles. A sample of 38 drivers was tested in emergency situations on a test track, and the drivers' behaviour was summarised as follows:

- drivers do not press the brake pedal simultaneously with steering,
- at higher vehicle speeds, drivers concentrate more on steering than braking,
- drivers make mistakes in operation.

Yamamoto and Kimura (1996) argued the increase in rollovers was not due to the characteristics of ABS, but either to drivers who become aggressive in their driving behaviour, relying too much on ABS to prevent crashes, or their inability to operate the ABS correctly. To describe the ABS anomaly Evans (1998) later put forward two postulates, based on anecdotal information:

1. Drivers never drive more slowly when their vehicles have ABS.
2. Some drivers, under certain circumstances, tend to drive a little faster because their vehicles have ABS.

Gibson and Crooks (1938; cited in Evans 1998) describe the theory whereby a driver adapts their driving as a result of a new safety measure, such that the safety benefit of any improved performance may be reduced. In regard to vehicle braking, Gibson and Crooks (1938; cited in Evans 1998) state "More efficient brakes on an automobile will not in themselves make driving the automobile any safer. Better brakes will reduce the absolute size of the minimum stopping zone, it is true, but the driver soon learns this new zone and, since it is his field-zone ratio which remains constant, he allows only the same relative margin between field and zone as before."

Evans (1998) notes that research does not support the suggestion that improved braking cannot affect overall crash risk. However, technical innovations that lead to observable differences in vehicle performance or handling characteristics are likely to be accompanied by changes in driver behaviour. Researchers in other areas of road safety have confirmed this experience. Herms (1972) found that pedestrians crossing at painted cross-walks were at a higher risk than at unpainted pedestrian crossings, a finding that was explained by the perception that the painted cross-walks were safer and led to behavioural adaptation in the form of careless crossing. Similarly, Jannssen (1994) demonstrated a 1% increase in speed as a result of behavioural adaptation to seat-belt wearing.

Evans (1998) evaluated rates of speed-related offences in ABS and non-ABS fitted vehicles. He found that drivers of ABS fitted vehicles had, with statistical significance, more speeding convictions (18 +/- 10%) when compared to non-speeding related offences and drivers of non-ABS fitted vehicles. However, there were significant shortcomings in the methods used to obtain this outcome and in the author's words the data should be interpreted as "little more than suggesting the possibility of an effect of sufficient magnitude to justify a more complete […] investigation."

Sagberg et al. (1997) studied the relationship between driver behaviour and two safety measures, one being ABS. The study was unobtrusive and data were obtained from film of taxi drivers in traffic travelling to Oslo airport. It was found that drivers of vehicles equipped with ABS had significantly shorter time headways. The only significant factor influencing the speed of the taxis was the hour of the day, suggesting that speed was determined more by surrounding traffic than by driver preference. Evans (1998) drew a link between reduced headways and increased travel speeds that may better explain the crash distribution of ABS-fitted vehicles. For example, the risk of a greatly dependent on rollover risk is extremely sensitive to vehicle speed. However, in the alternative it should be noted, as shown above, that ABS-fitted vehicles have significantly fewer nose to tail impacts, the reverse of which would be expected, based on the reduced headways results found by Sagberg et al. (1997).

Mazzae et al. (2001) undertook a comprehensive licence plate study to unobtrusively determine whether a difference in travel speed existed between ABS and non-ABS fitted vehicles. At several sites, laser gun speed measurements were taken during night and daylight hours, in both wet and dry conditions. Average speeds for location and conditions were compared for ABS and non-ABS fitted vehicles. No significant effect from ABS fitment on driving speed under any of the conditions considered was found. This led the authors to conclude that no behavioural adaptation due to ABS occurs in real-world driving, and therefore changes in the crash distributions due to the fitment of ABS cannot, according to this study, be attributed to behavioural adaptation.

It is clear from the literature that behavioural adaptation can, in certain circumstances, offset the benefits of a safety measure. However, in the case of vehicles equipped with ABS nothing has proven an association with increased speed. The results of Mazzae et al. (2001) strongly suggest that, whether existing in the past or not, there is currently no such behavioural adaptation to ABS. The available data is insufficient to conclusively link increases in certain crash configurations to driver behavioural adaptation. Therefore, alternative explanations require consideration.

Crash Avoidance with ABS

It is necessary to consider whether some driver response characteristic in ABS equipped vehicles, in emergency situations, is offsetting the potential safety benefits of ABS. One can speculate that crash avoidance behaviour can result in significantly different outcomes in ABS and non-ABS vehicles. A hypothetical scenario can be used to demonstrate this difference. Assume a vehicle in traffic stops suddenly and the driver of the tailing vehicle is forced to react quickly to avoid the imminent collision. The tailing vehicle will brake and possibly steer to avoid the crash. For a non-ABS equipped tailing vehicle the driver may lock the wheels and therefore lose steering control, with the vehicle either stopping in time, or impacting into the rear of the lead vehicle (see Figure 1.1). Alternatively, ABS will prevent wheel lock-up thereby maintaining steering. The ABS-equipped tailing vehicle may stop in time, impact into the rear of the lead vehicle, or avoid the crash by steering (see Figure 1.2). However, where the initial impact is avoided through steering past the lead vehicle, the driver is exposed to new hazards. Reflex crash avoidance steering may result in an impact with a stationary object (e.g. parked car or pole) or oncoming traffic, or loss of control (run-off-road rollovers) thereby exposing the occupant to impacts that are potentially of greater severity than the crash that was avoided. This highlights circumstances where ABS does not improve vehicle safety and can actually increase the severity of a crash and the risk of occupant injury.

Figure 1.1 Hazard avoidance with locked wheels, non-ABS (www.smartmotorist.com).

Car Without Antilock Brakes

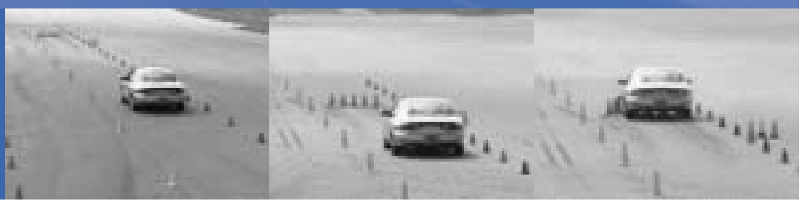


Figure 1.2 Hazard avoidance with ABS (www.smartmotorist.com).

Car With Antilock Brakes

Evans (1995) suggested that the very steering control that ABS provides allows steering inputs that translate into rollover, whereas the non-ABS equipped vehicle will skid out of control until striking a stationary object.

Mazzae et al. (1999a) and (1999b) investigated the effect of ABS on driver crash avoidance behaviour in an intersection scenario by using track testing and vehicle simulator testing. The aim of the research was to understand driver behaviour in emergency situations. The scenario used to elicit a crash avoidance response was a right-side intersection incursion. The key issues examined were:

- drivers tend to both brake and steer simultaneously during crash avoidance manoeuvres;
- drivers tend to make large, potentially excessive steering inputs during crash avoidance manoeuvres;
- drivers' crash avoidance manoeuvres in ABS-equipped vehicles result in road departures more often than in non-ABS-fitted vehicles;
- drivers avoid more crashes in ABS-equipped vehicles than in non-ABS-equipped vehicles on dry surfaces;
- drivers avoid more crashes in ABS-equipped vehicles than in non-ABS vehicles on wet surfaces.

In response to these issues they found that drivers tend to brake and steer simultaneously and make large and fast steering inputs. However, the steering inputs were not sufficient to cause significant road departures. A similar number of crashes were avoided in both ABS and non-ABS fitted vehicles on dry pavement, and a significantly larger proportion of crashes were avoided on wet pavement with ABS. The authors concluded that there is no correlation between driver crash avoidance behaviour and driver interaction with ABS, which would contribute to the apparent increase in single-vehicle fatalities that have been associated with ABS. It is necessary to regard this conclusion with caution for the following reasons:

1. Whilst the study was comprehensive in other respects, only one scenario, the intersection incursion was tested.
2. Few road departures were observed. The test incursion was not sufficiently "severe" to elicit an appropriate response. More severe test conditions may have caused a higher proportion of road departures, as it is only through observing road departures that any conclusion as to the cause of such departures can be reached.

Mazzae et al. (1999b) also note that the simulator and track tests were performed with alert and sober subjects and there was a suggestion that the influence of fatigue or alcohol may affect the behaviour of the subjects in an emergency manoeuvre.

Harless and Hoffer (2002) further analysed the data used by Farmer (2001) with reference to drink driving. The data was based on an analysis of GM vehicle lines that adopted ABS in 1992. They found that the increase in fatalities in ABS-equipped vehicles was confined largely to drink drivers. Fatal crash involvement among drinking drivers was 64% higher than expected based on exposure of vehicle lines and the number of drinking drivers involved in fatal crashes in the pre-ABS versions of the vehicles.

Inappropriate use of ABS

It could be expected that as the number of vehicles fitted with ABS increases, the population would become more familiar with the system and more educated as to its appropriate use. Therefore, caution must be exercised in using this old data as representative of current driver knowledge and behaviour. In support of this view, Harless and Hoffer (2002) found that the attenuation of the ABS anomaly (i.e. disproportionate fatality involvement) occurred after three or four years of vehicle service, which is most likely a result of increased driver skill with ABS after successive years of vehicle operation.

Collard and Mortimer (1998) analysed data from a Canadian public perception survey, where survey respondents were questioned as to the purpose and use of ABS. About 18% of the ABS users surveyed thought that pumping the brakes was the correct way to operate them, while close to 40% thought that the purpose of ABS was to stop faster, and/or prevent all skids, omitting the ability to steer as a function of ABS. Women under 40 years of age with the least understanding of ABS, evidenced by the incorrect identification of ABS operation and purpose, were more likely to report at least one collision than were women who demonstrated at least a partial understanding of ABS. Perron et al. (2001) found in a vehicle simulator and track tests that only 50% of drivers depressed the brake pedal with sufficient force to activate the ABS.

It is possible that the difference in the crash distribution of ABS and non-ABS-fitted vehicles can be partially attributed to incorrect operation and a lack of understanding of ABS. This conclusion is supported by results from Farmer (2001) and Hertz et al. (1998) who found a reduction in crash occurrence due to ABS as the vehicle aged. These researchers believe that the attenuation might have been a result of drivers becoming more educated and familiar with the operation of ABS.

2.4. ABS Track Test Performance

ABS will not substantially reduce stopping distances in dry conditions. However, in wet slippery conditions, ABS is very effective in reducing stopping distances. A locked wheel may provide higher deceleration than ABS on surfaces such as gravel and snow that allow a build up of material in front of a sliding wheel. The following literature has evaluated the track performance of ABS versus conventional braking on different surfaces.

Forkenbrock et al. (1998, 1999) performed a test track evaluation in an attempt to identify areas where ABS-fitted vehicles did not perform as well as their non-ABS-fitted counterparts. They evaluated the performance of nine production vehicles in seventeen stopping scenarios. Some of the scenarios included a straight-line stop, a straight-line stop with transition to different surface friction, a curve stop and a J-turn stop. Two different pedal applications were used and vehicles were tested in both lightly and heavily laden conditions. In most scenarios, ABS stopping distances were shorter than with the ABS disabled, the exception being gravel where stopping distances increased by an average of 27%. In almost all manoeuvres vehicle stability was superior when ABS was operational.

Marshek et al. (2002a, 2002b) used an ABS index of performance (ABSIP), i.e. the ratio of average ABS braking deceleration to locked wheel deceleration, to evaluate braking performance and characteristics. They conducted track tests on bitumen using six vehicles and found that deceleration in ABS-fitted vehicles was a significant function of vehicle speed. The results showed that both ABS and locked wheel braking varied significantly between vehicles. In general, ABSIP was greater than 1 at higher speeds (>35km/h) and less than 1 at lower speeds (<35km/h), indicating that ABS degrades braking performance at lower speeds and improves braking performance at higher speeds.

Strickland and Dagg (1998) also performed ABS track tests on dry asphalt. Straight line braking tests were completed on asphalt surfaces with different coefficients of friction (0.61 – 0.87) and at initial speeds from 38 km/h to 74 km/h. The data indicated that at speeds below 50km/h the average deceleration of ABS-equipped vehicles may drop to as low as 82% as that of standard braking system with locked wheels. Similar to Marshek (2002b), they found that as initial speed increased so did the braking efficiency of an ABS equipped vehicle.

Macnabb et al. (1998) investigated the relative stopping distance of seven vehicles fitted with ABS on gravel roads. They demonstrated that ABS significantly increased (up to 60%) stopping distances on gravel. The average deceleration with the ABS deactivated was between 0.59 and 0.66g and with the ABS operational, the average deceleration range was between 0.37 and 0.52g.

Eddie (1994) performed maximum braking tests on snow and ice surfaces with and without ABS. It was found that the average deceleration of the ABS equipped vehicle was slightly greater on ice than the non-ABS vehicle. However, in pavement tests in snow, the deceleration of the non-ABS-equipped vehicle was slightly greater than the same vehicle equipped with ABS. It was noted that loss of control of the vehicle occurred in several tests with vehicles not equipped with ABS but never with any ABS equipped vehicle.

2.5. Other Vehicles

This review focuses on the effect of ABS fitment primarily on passenger vehicle safety. However fitment of ABS to large vehicles and motorcycles is of equal relevance to their performance. The literature in this area is limited; nonetheless, a brief analysis is presented.

2.5.1. Light Trucks and Vans

Hertz et al. (1996) investigated the crash distribution of light trucks and vans (LTVs) fitted with both all-wheel ABS (AWAL) and rear-wheel ABS (RWAL). The data was separated according to ABS type. A significant reduction in non-fatal rollover crashes (36%) was associated with AWAL brakes. LTVs equipped with RWAL brakes exhibited a significant reduction in non-fatal rollover crashes and side impacts with fixed objects. However, significant increases in fatal and non-fatal frontal multi-vehicle crashes were found.

These data were updated by Hertz et al. (1998) and showed a predicted increase in AWAL vehicle rollovers and side impacts, i.e. both crashes associated with loss of control. For LTVs fitted with RWAL brakes there was no longer an increase in frontal crash occurrence.

Table 2.3 The change in crashes for light trucks and vans fitted with ABS. (Hertz et al, 1998)

ABS Type	Crash Severity	Crash Type	Road Type	% Change	95 % CL
AWAL	All	Roll	Favourable	-40	-54 to –40
AWAL	All	Roll	Unfavourable	-43	-60 to –20
AWAL	All	Run-off-road	Unfavourable	-33	-47 to –17
AWAL	All	Run-off-road	Favourable	-24	-35 to –12
AWAL	All	Side	Unfavourable	-35	-54 to –8
AWAL	All	Front	Unfavourable	-38	-46 to –29
AWAL	All	Front	Favourable	-14	-20 to –8
AWAL	Fatal	Roll	Favourable	+97	+34 to +190
AWAL	Fatal	Roll	Unfavourable	+125	+10 to +358
AWAL	Fatal	Side	Favourable	+111	+17 to +281
RWAL	All	Roll	Unfavourable	-39	-48 to –28
RWAL	All	Roll	Favourable	-42	-48 to –34
RWAL	All	Run-off-road	Favourable	-10	-17 to –3
RWAL	All	Side	Unfavourable	-30	-40 to –18
RWAL	All	Side	Favourable	-13	-22 to –2
RWAL	All	Front	Unfavourable	-10	-16 to –4
RWAL	Fatal	Roll	Unfavourable	+89	+3 to +246
RWAL	Fatal	Run-off-road	Favourable	-28	-44 to -7

The data are tabulated on the previous page, where a positive change indicates an increase in the risk of occurrence of a specific crash type in an ABS equipped vehicle relative to a non-ABS vehicle. The road type was classified as favourable if dry and free of debris etc., and as unfavourable if wet, snow-covered, or icy.

2.5.2. Motorcycles

Wakabayashi (1998) developed and applied an anti-lock brake system to a motor scooter. Track tests found that maximum deceleration levels were increased for beginner riders using ABS and decreased relative to expert rider braking. The authors felt that such a system was very positive, particularly for beginner riders as it reduced anxiety of a dangerous wheel lock-up during braking. Koch (2003) argues that ABS is even more important for motorcycles than for cars, yet in Germany only BMW and Honda offer ABS on their motorcycles. He quotes findings by the Institute of Vehicle Safety (Munich) according to which more than 70 deaths and 3000 crashes involving injury could be prevented each year by fitting ABS to motorcycles. Koch (2003) discusses reasons for the lack of ABS on motorcycles, which included: a negative image of ABS in motorcycle press, general overestimation by riders of their own skill, and track tests demonstrating superior braking without ABS by expert riders.

Real-life data regarding the effectiveness of ABS on motorcycles is very sparse. However, given the disproportionate numbers of riders injured and killed on the road, a wider introduction of motorcycle ABS requires further study and consideration. The EU-Commission is now supporting the introduction of motorcycle ABS as part of their overall campaign to reduce traffic deaths in Europe (Koch, 2003).

2.6. Effectiveness of Electronic Stability Programs (ESP)

ESP is a closed loop system that controls the dynamics of a vehicle by preventing or limiting lateral instability. Much in the same way as ABS prevents wheel lock-up, and traction control prevents wheel spin, ESP prevents the vehicle from “pushing out” of the turn or spinning out of the turn when it is steered (Automotive Handbook, 2000). Similar to ABS, ESP is a system that was introduced with the aim of reducing the occurrence and severity of crashes.

Tingvall et al (2003) studied data from accidents occurring in Sweden between 2000 and 2002 in an attempt to estimate the influence of ESP on the reduction of real-life injuries. The data included 442 crashes involving ESP equipped vehicles and a control group of 1967 non-ESP vehicle crashes. The results were based on the assumption that the benefit of ESP in avoiding rear impacts on dry roads was negligible (ESP and control vehicles were all equipped with ABS). The study showed positive benefits of ESP, particularly on low friction surfaces. The overall effectiveness in reducing crash involvement was 22.1 ± 21%, for accidents on wet roads the effectiveness was 31.5 ± 23.4%, and on ice or snow covered roads the effectiveness was 38.2 ± 26.1%. The study also considered the difference in crash exposure between ESP equipped and non-ESP equipped vehicles that were front wheel drive and rear wheel drive of large and small sizes. ESP was found to be effective for three different types of cars: small and large front wheel drive vehicles, and large rear wheel drive vehicles.

Fennel (2003) presented German crash data for Mercedes Benz vehicles. Since the introduction of ESP as standard equipment on all Mercedes passenger vehicles in 1999, there has been a 15% reduction in crash occurrence for these vehicles. The crash configuration where a driver loses control without the influence of another vehicle accounts for an average of 15% of crashes for all German vehicles. In 1998, this type of crash accounted for 15% of Mercedes crashes. However, this dropped to 10.6% in 1999 with the introduction of ESP as a standard feature. Similarly, Mercedes rollover crashes have reduced by 12%, demonstrating a large positive effect on the safety benefits of ESP.

Langweider et al. (2003) attempted to predict the potential benefits of ESP by analysing real-world crash data. The basis for the research was the premise that ESP can prevent loss of control of a vehicle. Therefore, by determining the distribution of loss of control crashes, an indication of the potential effectiveness of ESP can be reached. Loss of control was observed in 25% to 30% of all passenger vehicle crashes involving personal injury. The authors also suggested that a reduction of up to 9% in the number of serious crashes involving trucks was possible with ESP. Langweider et al. (2003) attempted to highlight the maximum possible benefits of ESP. However, they acknowledged that further research activities are required to find a more precise quantitative determination of the crash avoidance potential of ESP.

Aga and Okada (2003) analysed crashes in Japan for three Toyota passenger vehicles fitted with and without Vehicle Stability Control (VSC). The crash rate of the VSC fitted vehicles relative to non –VSC fitted vehicles showed approximately: a 35% reduction in single-vehicle crashes, a 30% reduction in head-on multi vehicle crashes, and respectively, a 50% and 40% reduction in accidents where severe and moderate vehicle damage occurred. The casualty rate of vehicles with VSC was estimated to have reduced by 35% for both single-vehicle collisions and head-on collisions.

The initial data analysis shows a very positive influence of ESP on safety. More comprehensive data that allow the effectiveness of ESP in improving safety in all surface conditions (i.e. wet, dry and icy) and for all types of crash configuration are required. As noted by Aga and Okada (2003), it is important to emphasise that VSC cannot prevent all crashes or compensate for all driver errors and that it is not a substitute for safe and intelligent driving practices.

2.7. Other Braking and Stability Control Systems

This section offers a description of a number of braking-based active safety systems. Unfortunately, there is little data regarding the "real-world" effectiveness of these systems.

2.7.1. Traction Control Systems

Traction Control Systems prevent wheel spin by a combination of control of engine power and individual braking of wheels. Wheel sensors, usually the same as those used by the ABS system, detect any wheel spin, and ECU limits engine power and increases brake pressure at the spinning wheel. The system performs two functions (Automotive Handbook, 2000):

1. It enhances traction.
2. It helps maintain vehicle stability.

By preventing wheel spin, traction is maintained at a high level and enables a vehicle with sufficient power to spin its wheels to accelerate faster. When a wheel spins, it loses both lateral and longitudinal traction. The loss of lateral traction can adversely affect vehicle stability. In front wheel drive vehicles, wheel spin will tend to cause a vehicle to understeer and the driver is unable to maintain the desired cornering path. In a rear wheel drive car spinning wheels will tend to cause oversteer, which may lead to loss of control and a spin out. The prevention of this type of crash is one of the major potential benefits of traction control.

2.7.2. Emergency Brake Assist System

The inability of inexperienced drivers to apply sufficient force to the brake pedal in emergency situations (Käding and Hoffmeyer, 1995) has led to the development of brake assist technology. Inadequate pedal pressure means that a vehicle will not brake to its maximum potential. By detecting an emergency brake situation, emergency brake assist systems apply maximum braking force, usually to the point of operating anti-lock brakes, thereby ensuring that stopping distances are minimised. Emergency braking can be detected by the pedal travel speed and stroke (Hara et al., 1998). This system has the potential to reduce stopping distances in an emergency situation and is therefore seen as a positive safety initiative.

2.7.3. Brake Distribution Systems

There are a number of brake distribution systems which serve different purposes, but they all operate in a similar manner, by controlling the brake pressure to individual wheels (and sometimes controlling engine power, steering and suspension). The systems include ESP, roll stability control, cornering brake control and electronic brake force distribution. The systems detect a danger, such as potential rollover or spinout, and attempt to restore the vehicle to a stable condition. This is achieved by controlling the dynamics of the vehicle by applying predetermined braking input.

2.8. Summary

An analysis conducted by Garrott and Mazzae (1999) best summarises the overall performance of ABS as documented in the literature. ABS has consistently been associated with a decrease in multi-vehicle and pedestrian crashes, and an increase in single-vehicle road departure crashes. ABS has been shown to increase the risk to occupants of the vehicle fitted with ABS. However, ABS provides a significant safety benefit to other road users (pedestrians etc.) and occupants of other vehicles. From a road safety perspective, balancing increased risk to ABS vehicle occupants with decreased risk to other road users, there is no apparent overall benefit or disbenefit from the fitment of ABS.

The type of surface is a strong determinant of crash risk involving ABS vehicles. In unfavourable conditions any benefits of ABS are magnified. However, in favourable conditions it is the disadvantages that are magnified.

Track test data clearly shows that for most manoeuvres stopping distances are smaller in ABS-fitted vehicles than non-ABS fitted vehicles, particularly on wet or icy surfaces. Exceptions are on dry bitumen, where braking performance at higher speeds (>~35-50km/h) with ABS is greater than locked wheel braking. However, at lower speeds the performance of ABS is worse than locked-wheel braking. Also, stopping distances on snow and gravel are greater in an ABS vehicle. However, vehicle stability is significantly greater when stopping in an ABS-equipped vehicle.

There is no consensus in the literature on the reason for the difference between the crash distributions of ABS-fitted vehicles and vehicles with a conventional braking system. The explanation that behavioural adaptation in the form of increased speeds is the cause of the difference is unlikely given the findings by Mazzae et al. (2001). Importantly, updated data from Hertz et al. (1998) and Farmer (2001) have shown an attenuation of the association of ABS with increased single-vehicle crashes. This suggests that as drivers become more familiar with their ABS they have fewer crashes. Therefore, a lack of understanding of ABS operation could justify increases in single-vehicle crashes. This also justifies the need for an ongoing evaluation of the effects of ABS.

The continued development of active safety features shows considerable promise in improving road safety. Recent European data evaluating the introduction of ESP in vehicles have shown a high level of effectiveness in improving safety.

3. Data Sourcing

3.1. Crash Data

Drivers

Police reported crash data from Victoria, NSW and Queensland formed the basis of the crash data used in this study. The data cover 686,383 vehicles manufactured over the period 1982-98 and crashing during the years 1987-98. The data have previously been used to create an extensive crash and injury database for use in the rating of Australian passenger cars with regard to their crashworthiness (Newstead et al, 2000) and were sufficient to reliably rate the crashworthiness of 167 individual vehicle models.

Vehicle crashworthiness ratings produced by Newstead et al. (2000) are based only on driver injury outcome, as injury outcome for vehicle occupants other than drivers are not reliably recorded in the crash data, particularly when the other occupants are uninjured. Consequently the crash data files assembled for estimation of crashworthiness ratings cover only the injury status of the driver. In this study, a subset of the drivers of vehicle models identified as relevant, based on ABS availability, was used. A full description of the data assembled for estimation of crashworthiness ratings appears in Newstead et al. (2000).

3.2. Availability of ABS

The availability of ABS and other vehicle safety features for particular vehicle models was determined as part of an earlier evaluation of vehicle safety feature effectiveness (Newstead et al, 2002). The process of identification of ABS availability and the presence or absence of ABS is detailed below.

Vehicle model details were derived for vehicles appearing in the crash data used for crashworthiness ratings through a process of Vehicle Identification Number (VIN) decoding described in Newstead et al 2000. Using the decoded vehicle model information, it was then possible to identify the vehicle model series that had ABS as an option. However, it was generally not possible to identify whether ABS was fitted to a vehicle from examination of the VIN. In order to identify safety equipment fitted to a particular crashed vehicle it was necessary to return the VIN to the vehicle manufacturer to be compared against vehicle build information. This necessitated gaining the co-operation of vehicle manufacturers to undertake this task.

Twelve car manufacturers were initially approached to provide optional vehicle safety feature information on vehicles involved in real-world crashes. Data from six car manufacturers (Ford, Holden, Honda, Mitsubishi, Toyota, and Volvo) ultimately proved useful in the analysis. A key requirement of the vehicle manufacturers in their agreement to supply data for the project was that the performance of vehicle safety features in identified specific vehicle models would not be reported. To comply with this requirement, results presented in this report give either overall performance of ABS without reference to the vehicle models contributing to the average across all models or are de-identified with respect to vehicle model if model specific results are quoted. All model specific information presented uses a surrogate model code.

Participating manufacturers were provided with the VIN of crashed vehicles and were requested to identify whether or not ABS and other vehicle safety features were fitted to these vehicles.

3.3. Matched Crash and Vehicle Safety Features Data

Drivers

Data on vehicle safety options returned from the vehicle manufacturers was merged with the 686,383 observations in the crashworthiness data from NSW and Victoria 1987-1998 and Queensland 1991-1998 consisting of driver information only. The matching process resulted in 40,739 records with an indication of the presence or absence of ABS. This provided sufficient data to enable analysis of the effectiveness of ABS.

4. Method

Anti-lock Brake Systems (ABS) prevent a vehicle's wheels from locking during heavy braking, which allows the driver to maintain steering control as the vehicle rapidly decelerates. As such, they are fundamentally considered a primary safety feature concerned with crash avoidance rather than injury mitigation given crash occurrence. It is possible, however, that the provision of controlled maximum braking force by ABS may have some secondary safety effects in crashes by lowering impact speeds and hence total crash severity. Therefore, the potential benefits of ABS are analysed in terms of both primary and secondary safety.

Secondary safety refers to the risk of injury given that a crash event has occurred. The aim of the analysis of secondary safety is to examine whether vehicles fitted with ABS have the same level of secondary safety as their counterparts without ABS. The measures of secondary safety used in this study are injury risk and injury severity and are the same as those used in the study of Australian Vehicle Crashworthiness by Newstead et al. (2000). They are defined as follows.

- *Injury Risk* is the probability of injury given involvement in a crash severe enough for at least one vehicle to be towed from the scene.
- *Injury Severity* is the probability of death or serious injury (hospitalisation) given that an injury is sustained.

Primary safety refers to the ability of a vehicle to avoid a crash. It is generally difficult to directly measure changes in primary safety as there is a lack of sufficiently detailed vehicle exposure information for use in the direct estimation of crash risk. Consequently, the assessment of the primary safety benefits of ABS reported here focuses on the difference in distribution across various crash type groups of the ABS and non-ABS equipped vehicles. Absolute crash risk is estimated using side impact crashes, where the ABS equipped vehicle is the target vehicle, as an induced exposure measure. If the ABS was effective in increasing primary safety, it would be expected that ABS-equipped vehicles would have been involved in a lower proportion of those crash types for which ABS might be expected to have the most effect.

The following sections describe the methodology used in this report to assess changes in primary and secondary safety associated with the presence of ABS.

4.1. Hypotheses

4.4.1. Secondary Safety

The first hypothesis tested concerned the measures of injury risk and severity being used to reflect vehicle secondary safety. The null hypothesis tested is that vehicles fitted with ABS have the same probability of occupant injury risk or severity in a crash as equivalent vehicles without the safety feature. This is assessed against the two-sided alternative hypothesis that vehicles fitted with ABS have different levels of injury risk or severity when compared to equivalent non-ABS equipped vehicles. Given that ABS is designed to improve occupant protection, it may have been considered more appropriate to use a one-sided alternative hypothesis that assumes any observed effect to be a reduction in injury. However, other research has shown that, in some circumstances, vehicle safety features can reduce safety. Therefore, the more conservative two-sided alternative hypothesis was considered appropriate. If a one-sided alternative hypothesis is favoured, statistical significance values quoted can be halved to give the one-sided values. Point estimates of effectiveness do not change. A two sided hypothesis test will allow accurate assessment of both increases and decreases in injury due to the presence of ABS whereas, a one sided test will only allow injury decreases to be detected but will do so with greater statistical power.

4.1.2. Primary Safety

As described, assessment of the primary safety effects of ABS centres on comparing the distribution of crash types between ABS and non-ABS equipped vehicles. The null hypothesis being tested is that given that a crash has occurred, there is no difference in the risk of involvement in crashes of various types attributable to the presence or absence of ABS. This is assessed against the alternative hypothesis that the risk of involvement by crash type differs between vehicles with and without ABS. There is no concept of a one-sided or two-sided alternative hypothesis when testing for differences in risk in this way.

Estimating the absolute crash risk of vehicles with ABS also assessed the impact of ABS on the absolute risk of crash involvement. This required the use of an induced exposure measure to approximate the proportion of vehicles equipped with ABS. The hypothesis being tested is that vehicles fitted with ABS are at no greater or less risk of involvement in a casualty crash when compared to vehicles not fitted with ABS.

4.2. Assessment of Secondary Safety Effects

In assessing the effects of ABS on secondary vehicle safety, it was not sufficient to simply compare injury experience across occupants of all vehicles fitted with ABS with those not fitted with ABS. Approaching the analysis in this way would potentially have led to the difference in average total safety between vehicles in the ABS fitted and non-fitted groups being confounded with the effect of ABS itself. This is because not all vehicle models assessed in the study had the same proportion fitted with ABS. To overcome this problem, the analysis design capitalised on the fact that ABS was present and absent in the same vehicle model involved in crashes. The differences in secondary safety between vehicles of the same model, with ABS fitted and not fitted, were assessed. The average safety effect of ABS was obtained by averaging the effects across the individual vehicle models assessed. This approach controls for the inherent difference in overall safety between different vehicle models in estimating the average effect of ABS. A Poisson Log-Linear statistical analysis technique was employed to estimate the effectiveness of ABS and is described in detail below.

Because the analysis design used requires assessment of the safety benefits of ABS at the individual vehicle model level, it was important for the success of the analysis to have sufficient numbers of crashed vehicles with occupant injuries at all severity levels for each vehicle model. For this reason, individual vehicle models with small frequencies in each or any level of injury severity of the occupant relevant to ABS were excluded from the analysis.

Assessing the secondary safety effects of ABS in the above way assumes that factors known to affect injury outcome, such as occupant age and sex and average crash severity, are the same within each vehicle model for vehicles with and without ABS. Interrogation of the data on the available variables reflecting occupant and crash characteristics suggested that this was true. In order to formally test this, a logistic regression analysis was employed. This enabled estimation of the effect of ABS on injury outcome whilst simultaneously controlling for the effect of factors other than the presence of ABS. The logistic regression analysis procedure is also described below. Results from the logistic regression analysis were used only to assess the assumption of balance of other factors between comparison vehicles. If the assumptions proved justified, the results from the Log-Linear analysis were considered the more definitive as this method gave greater statistical power due to fewer parameters being included in the models.

4.2.1. Contingency Table Analysis

Assessment of differences in occupant injury risk and injury severity between crashed vehicles with and without ABS without adjusting for differences in other factors between the comparison vehicle groups was made using a contingency table analysis. Table 4.1 shows the design of the contingency table used to analyse differences in occupant injury risk or severity between vehicles with and without ABS. In Table 4.1, N represents the number of occupants of crashed vehicles with or without ABS at the particular level of occupant injury indicated. The injury levels in brackets are for the injury severity analysis whilst the levels without brackets are for the injury risk analysis. Because the data for analysis relate to one occupant in a crashed vehicle, the entities making up the counts N can be considered independent. When assessing the effectiveness of ABS, only the vehicle driver injury status was considered. The driver is generally the vehicle occupant with the highest exposure and most serious injuries.

Table 4.1 Contingency table layout for analysis of secondary safety effects

Vehicle Model	ABS Not Fitted		ABS Fitted	
	Not Injured (Minor Injury)	Injured (Serious Injury)	Not Injured (Minor Injury)	Injured (Serious Injury)
1	N_{111}	N_{112}	N_{121}	N_{122}
2	N_{211}	N_{212}	N_{221}	N_{222}
J	N_{j11}	N_{j12}	N_{j21}	N_{j22}

A log-linear model with Poisson error structure, appropriate for the variability in the counts of occupant casualties, was then fitted to the data, with the model form given by Equation 1. The log-linear model form of Equation 1 can easily be fitted in common statistical software packages such as SAS.

(Equation 1) $$\ln(N_{ijk}) = \beta_0 + \beta_i + \beta_{ij} + \beta_{ik} + \beta_{ijk}$$

In Equation 1, i is the vehicle model index, j is the ABS presence indicator (yes or no), k is the injury level index (not injured or injured for the injury risk analysis or minor or serious injury for the injury severity analysis). The _ values are the model parameters and N_{ijk} is the cell crash count. The percentage reduction in injury or severity injury associated with the presence of ABS in vehicle model i is given by Equation 2.

(Equation 2) $$\Delta_i = 100 \times (1 - \exp(\beta_{ijk}))\%$$

Statistical significance of Δ_i is equal to the statistical significance of _ $_{ijk}$, obtained directly from the fitted log-linear model. Confidence limits for Δ_i are computed in the normal way using the estimated standard error of _ $_{ijk}$ obtained from the fitted log-linear model and using the transformation given by Equation 2.

It should be noted that estimates of the effectiveness of ABS obtained from the log-linear model reflect a change in the odds of injury or odds or severe injury associated with ABS rather than the absolute change in the injury risk or severity measure directly. Injury risk odds are the ratio of injured to uninjured occupants whilst injury severity odds are the ratio of fatally injured or hospitalised occupants to those with minor injuries. Estimates of safety feature effectiveness presented in the results reflect percentage reductions in the injury or severity odds ratios associated with the presence of ABS. Whilst this measure does not reflect directly the hypothesis being tested as stated, indirectly, it is testing the stated hypothesis and statistical significance values given are directly relevant.

Modification to the above model can be made to estimate average safety feature effect across all represented vehicles. The modification required is shown in Equations 3 and 4.

(Equation 3) $$\ln(N_{ijk}) = \beta_0 + \beta_i + \beta_{ij} + \beta_{ik} + \beta_{jk}$$

(Equation 4) $$\Delta = 100 \times (1 - \exp(\beta_{jk}))\%$$

4.2.2. Logistic Regression Analysis

The logistic regression analysis methods used to estimate the effects of ABS in injury risk and severity whilst adjusting for the effects of external factors are an extension of those used for estimation of crashworthiness ratings by Newstead et al. (2000).

The logistic model of a probability, P, is of the form given in Equation 5.

(Equation 5) $$\log it(P) = \ln\left(\frac{P}{1-P}\right) = \beta_o + \beta_1 X_1 + \ldots + \beta_k X_k = f(X)$$

That is, the log of the odds ratio is expressed as a linear function of k associated variables, X_i, i + 1, ..., k. Estimates of the parameter coefficients of the logit function, i.e. the $\hat{\beta}_i$ can be obtained by maximum likelihood estimation (Hosmer & Lemeshow, 1989). The extension of this model to include interaction terms is straightforward.

As in Newstead et al. (2000), the factors included in the logistic regression model that were available in the data and known to affect both injury risk and injury severity, apart from ABS, are given in Table 4.2. Logistic models were obtained separately for injury risk and injury severity.

Table 4.2 Factors associated with injury outcome present in the crash data

Factor (Injury Severity)	Categories
Driver or passenger sex	Male, Female
Driver or passenger age	≤25 years, 26-59 years, _60 years
Speed limit at the crash location	≤75 km/h, _80 km/h
Number of vehicles involved	Single vehicle, >1 vehicle
State of crash	NSW, Victoria, Queensland
Year of crash	1997, 1988, …,1998
Vehicle Model	A, B, C, etc.

Following the methods of Newstead et al. (2000), a two-stage approach to fitting each logistic regression model was used. First, a stepwise procedure was used to identify the factors from Table 4.2 other than vehicle model and the factors significantly associated with the injury measure being estimated. To ensure model estimate convergence in a reasonable time frame, a hierarchical structure was imposed so interactions between variables were included in the model only when the corresponding main effects were also included. The resultant logistic regression models were referred to as the “covariate” models or equations. In the second stage of analysis, the model was re-estimated to include the factors in the covariate model along with vehicle model, an indicator of ABS presence and the interaction between vehicle model and the ABS indicator. The inclusion of the base effects of the vehicle model and ABS presence enabled the estimation of average ABS effectiveness across all vehicles in the analysis. The inclusion of the interaction term between vehicle model and the indicator of ABS presence facilitated estimates of safety feature effectiveness by vehicle model.

All data were analysed using the Logistic Regression procedure of the SAS statistical package (SAS Release 8.2, 1999-2001 by SAS Institute Inc., Cary, NC, USA). Estimates of the coefficients of the logit function, together with their associated standard errors, were obtained by maximum likelihood estimation. In the modelling process, design variables for the various factors were chosen in such a way that the estimated coefficients represented deviations of each of the variable levels from a reference level.

4.3. Assessment of Primary Safety Effects

4.3.1. Comparison of Distributions

Assessment of the primary safety effects of ABS has centred on examining changes in distribution of crash types associated with ABS equipped vehicle compared to non-ABS equipped vehicles.

Within the available crash data, there are two different means of describing crash type. Victorian and Queensland crash data both use the Definition for Classifying Accidents (DCA) system whilst New South Wales use the Road User Movement (RUM) system. Broadly the two crash type variables give the same type of information about crash configuration (for example rear end, run off left on straight, fell from vehicle, etc.). However, it is not possible to re-code the categories in one system to be entirely compatible with the other. This necessitated parallel rather than combined analysis of RUM and DCA crash type data.

Analysis of crash type by each crash type in the DCA or RUM crash classification system was not possible due to small data quantities in the defined cells. Instead, crash types were aggregated into the 10 broader crash type groupings for analysis based on the first digit of the RUM code and first two digits of the DCA code.

Testing for differences in distribution by crash type between ABS and non-ABS-equipped vehicles was carried out using a standard chi-squared test of independence. Data were presented in a 2x10 category contingency table defined by ABS presence or absence and the 10 broad crash type groups. Testing of the null hypothesis, described in Section 4.1.2, amounted to testing the independence of the ABS and crash type categories in the contingency table using the standard chi-squared test. The test statistic is as follows.

(Equation 6)

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where O_i = the observed number of cases in cell i;

E_i = the expected number of cases when H_0 is true (ABS presence and crash type are independent); and

k = the number of categories.

H_0 will be rejected if the calculated value of χ^2 is greater than the critical value of χ^2 with 9 degrees of freedom at the 5 percent level of significance. The critical value is obtained from statistical tables.

4.3.2. Estimation of Absolute Risk of Crash Involvement

The comparison of the distribution of ABS and non-ABS equipped vehicles by crash type does not provide information on the effect of ABS on the absolute risk of crash involvement. In order to estimate this effect, it is necessary to consider the relative exposure of ABS and non-ABS equipped vehicles in the traffic system. Due to a lack of sufficiently detailed vehicle exposure information, direct calculation of absolute crash risk is not possible. However, an induced exposure measure may be used to estimate the prevalence of ABS vehicles in the vehicle fleet and consequently any difference in the absolute crash risk of ABS and non-ABS equipped vehicles. Therefore, the hypothesis being tested is that vehicles fitted with ABS are at no greater or less risk of involvement in a casualty crash in comparison to vehicles not fitted with ABS.

In this study, side impact crashes, where the vehicle under consideration is the target vehicle, have been selected as the induced exposure measure. The selection of this crash type is based on the assumption that the frequency of side impact crashes does not differ between vehicles fitted with ABS and those not fitted with ABS. This assumption is discussed further in Section 5.2.2.

The methodology used to estimate the absolute risk of crash involvement follows closely that used by Evans in his study on the risks associated with different crash types (Evans, 1998). First, the ratio of the crash type of interest to side-impact crash is calculated. This ratio is defined as:

(Equation 7)
$$R = \frac{N_{ABS(I)} \times N_{NABS(S)}}{N_{ABS(S)} \times N_{NABS(I)}}$$

where,

$N_{ABS(I)}$ the number of vehicles fitted with ABS involved in the crash type under examination where the driver was injured (N_1)

$N_{ABS(S)}$ the number of vehicles fitted with ABS involved in side impact crashes where the driver was injured (N_2)

$N_{NABS(I)}$ the number of vehicles not fitted with ABS involved in the crash type under examination where the driver was injured (N_3)

$N_{NABS(S)}$ the number of vehicles not fitted with ABS involved in side impact crashes where the driver was injured (N_4)

From this ratio it is possible to estimate the percentage change in risk associated with the presence of ABS using the following formula:

(Equation 8)
$$\Delta Risk = 100(1 - R)\%$$

In order to provide confidence limits on the estimated ratio of the crash type of interest to side impact crashes, it is necessary to consider the error structure. In this study, the choice of error structure is dictated by the natural bounds of the estimated ratio. To ensure that R is contained with the bounds 0 to infinity, the logarithm of R is used to calculate the standard error. The standard error associated with the estimate of R is given by:

(Equation 9)
$$\sigma_{\ln(R)} = \sqrt{\sum_{i=1}^{4} \frac{1}{N_i}}$$

and the 95% confidence limits by:

(Equation 10)
$$R_{\text{Lower Limit}} = \exp\left(\ln(R) - 2\sigma_{\ln(R)}\right)$$

(Equation 11)
$$R_{\text{Upper Limit}} = \exp\left(\ln(R) + 2\sigma_{\ln(R)}\right)$$

The confidence limits on the percentage change in risk associated with the presence of ABS can be easily derived from equations 8, 10 and 11.

5. Results

5.1. Secondary Safety SAFETY

5.1.1. Injury Severity

Table A1 in the appendix, lists the driver injury severity by vehicle anti-lock brake presence for each of the vehicles in the study. It shows that there were sufficient data for seven vehicle models to allow assessment of the effects of ABS on driver injury severity using the contingency table analysis method. Table 5.1 gives the number of cases for each of these seven vehicle models classified by ABS presence and driver injury severity level.

Table 5.1 Anti-lock Brake Presence and Injury Severity by Vehicle Model and Overall

Vehicle Model	Not Fitted			Fitted			Total	% Reduction in Injury Severity Odds* Associated with ABS Presence** (Statistical Significance)
	Injury Severity			Injury Severity				
	Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	Total	
F	456	147	603	341	123	464	1,067	-11.90 (0.4276)
L	622	210	832	375	122	497	1,329	3.64 (0.7776)
O	8	5	13	13	9	22	35	-10.77 (0.8865)
Q	529	144	673	425	114	539	1,212	1.46 (0.917)
AA	407	105	512	15 3	18	530	22.48	(0.6916)
LL	7	3	10	21	17	38	48	-88.89 (0.4047)
RR	492	141	633	45	12	57	690 (0.8315)	6.95
							Average Effect	**-1.59 (0.8346)**

** Injury severity odds are the ratio of serious injuries to minor injuries*
***Negative values indicate an estimated increase in injury severity odds associated with ABS presence.*

Estimates of the influence of ABS on driver injury severity in Table 5.1 suggest the presence of ABS is associated with a statistically non-significant average 1.6% increase in injury severity across the seven vehicle models for which sufficient data was available. Results for individual vehicle models varied widely from a 22% reduction to an 89% increase with 4 out of the 7 vehicle models indicating a decrease in injury severity associated with ABS presence. As none of these estimates were statistically significant any interpretation of these results should be made with extreme caution.

Logistic regression analysis was undertaken to assess whether factors affecting driver injury severity other than the vehicle model and ABS were biasing the estimates of ABS effects on injury severity obtained from the contingency table analysis. The logistic regression analysis found no statistically significant relationship between driver injury severity and ABS presence either overall or by particular vehicle model. Further, point estimates of ABS effects on driver injury severity from the logistic regression modelling were consistent with those from the contingency table analysis. This suggests that factors affecting injury severity other than ABS were evenly balanced between vehicles within a particular model with and without ABS. Given the consistency of the results between the two methods of analyses, detailed results from the logistic regression modelling are not presented here. Results from the contingency table analysis are considered to represent the best analysis from the available data as this method gives greater statistical power.

5.1.2. Injury Risk

Analysis of the effects of ABS on the risk of driver injury given crash involvement was carried out in the same manner as for injury severity above. Victorian crash data were excluded from the analysis as only crashes involving injury are reported in that state. In contrast, all crashes involving towing of at least one vehicle are reported in NSW and Queensland. By excluding the Victorian crash data, the estimates of injury risk will not be biased by the under reporting of uninjured drivers in Victoria.

Table A2 in the appendix lists all vehicle models by ABS presence and the level of driver injury for injury risk calculation (injured or uninjured). There were sufficient data for eleven models to be

Table 5.2 Anti-lock Brake Presence and Injury Risk by Vehicle Model and Overall

Vehicle Model	Not Fitted			Fitted			Total	% Reduction in Injury Risk Odds* Associated with ABS Presence** (Statistical Significance)
	Injury Risk			Injury Risk				
	Not Injured	Injured	Total	Not Injured	Injured	Total		
F	3,510	506	4,016	2,632	391	3,023	7,039	-3.05 (0.6769)
L	4,478	718	5,196	2,585	413	2,998	5,495	0.36 (0.9572)
O	106	11	117	90	17	107	224	-82.01 (0.1466)
Q	3,649	529	4,178	2,838	411	3,249	7,427	0.10 (0.9882)
AA	2,457	350	2,807	110	9	119	2,926	42.56 (0.1146)
BBB	55	10	65	72	15	87	152	-14.58 (0.7601)
HH	91	11	102	29	4	33	135	-14.11 (0.8319)
LL	95	8	103	162	25	187	290	-83.25 (0.1553)
NN	49	4	53	23	3	26	79	-59.78 (0.5602)
RR	3,368	483	3,851	274	38	312	4,163	3.29 (0.8523)
SS	90	10	100	21	5	26	126	-114.28 (0.2032)
							Average Effect	**-1.33 (0.7293)**

** Injury risk odds are the ratio of injured to uninjured drivers*
***Negative values indicate an estimated increase in injury severity odds associated with ABS presence.*

included in the analysis of ABS effects on injury risk. Table 5.2 gives the number of cases for each of these eleven vehicle models classified by ABS presence and driver injury risk level.

Table 5.2 shows that for seven of the eleven vehicle models, the presence of ABS was associated with an increase in driver injury risk odds. The average increase in injury risk odds across all eleven vehicle models considered was 1.3%, with values for individual models ranging from an increase of 114% to a reduction of 43%. However, as for the injury severity analysis, none of the estimated changes in injury risk odds associated with the presence of ABS were statistically significant. Again, any interpretation of the results presented should be made with extreme caution.

Logistic regression analysis was undertaken to assess whether factors affecting driver injury risk other than the vehicle model and ABS were biasing the estimates of the effect of ABS obtained from the contingency table analysis. The logistic regression analysis found no statistically significant relationship between driver injury risk and ABS presence either overall or by particular vehicle model. Further, point estimates of ABS effects on driver injury severity form the logistic regression modelling were consistent with those from the contingency table analysis. This suggests that factors affecting injury severity other than ABS were evenly balanced between vehicles within a particular model with and without ABS.

As for the injury severity analysis, detailed results from the logistic regression modelling are not presented here because the results from the contingency table analysis are considered to be the most definitive.

5.2. Primary Safety

5.2.1. Analysis of Crash Distribution

Assessment of the primary safety effects of ABS brakes has been undertaken by examining differences in crash distribution between ABS equipped and non-equipped vehicles using the methods described in Section 4.3.1. As noted, due to the differences between the DCA and RUM system for describing crash configuration, analysis of ABS effects on crash type has been undertaken separately for each crash type definition.

Table A3 in the appendix lists crash DCA by driver injury severity and ABS presence for data from Queensland and Victoria. Data in Table A3 have been aggregated by the ten broad crash categories under which the individual classifications are defined. The aggregated data are presented in Table 5.3 along with the percentage of data in each of the 10 categories for ABS and non-ABS equipped vehicles. The percentages allow direct comparison of the distribution of crashes within each ABS category. The percentage crash distribution within each ABS category is also plotted in Figure 5.1. It should be noted that the data in Table 5.3 include only crashes involving injured drivers in order to overcome the problem of different crash reporting criteria between Victoria (casualty crash reporting requirement) and Queensland (all tow-away crash reporting requirement). Failure to make this restriction may have resulted in a bias in the analysis.

A chi-squared test of independence of the data in Table 5.3 showed a statistically significant different distribution of crashes by crash type between ABS and non-ABS equipped vehicles ($\chi^2(9)=78.8$, $p<0.001$). In particular, ABS-equipped vehicles were under-represented in crashes coded as ‘manoeuvring’ or ‘pedestrian’ in comparison to non-ABS equipped vehicles. In contrast, ABS-equipped vehicles were over-represented in comparison to non-ABS equipped vehicles in crashes where a vehicle left a straight or curved section of carriageway (i.e. ‘off path on straight’ or ‘off path on curve’). It is noted that these results do not give any information about the relative crash risk of ABS and non-ABS equipped vehicles but only about the types of crashes in which they are involved.

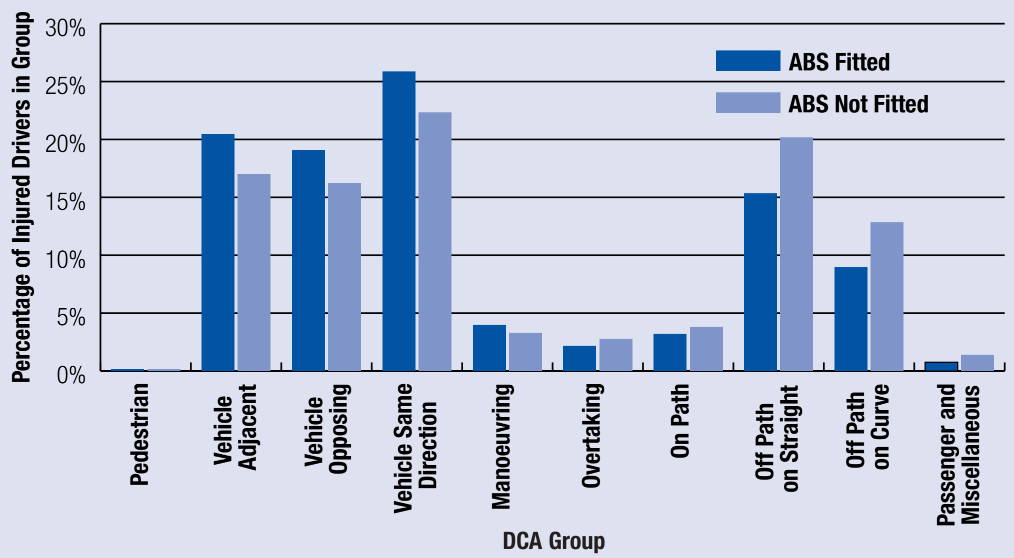
A parallel analysis to that presented in Table 5.3 and Figure 5.1 for DCA crash classification was carried out for the NSW data using RUM crash type coding. This is presented in Table 5.4 and Figure 5.2. The full table of crash frequency by RUM crash type and driver injury severity is given in Table A4 in the appendix. Again only crashes involving driver injury have been included in the formal analysis to give results comparable to the DCA analysis above.

As with the DCA analysis, a chi-squared test of independence of the RUM data in Table 5.4 showed a statistically significant different distribution of crashes by crash type between ABS and non-ABS equipped vehicles ($\chi^2(9)=117.0$, $p<0.001$). The examination of crash distributions in Table 5.4 and Figure 5.2 leads to similar conclusions as drawn from the DCA analysis. That is, given crash

Table 5.3 **ABS Brake Presence by DCA Crash Group: Victoria and Queensland**

DCA Group	ABS Not Fitted	ABS Fitted	Total
Pedestrian	4 (0.15%)	1 (0.13%)	5
Vehicle Adjacent	530 (20.45%)	134 17.01%)	664
Vehicle Opposing	495 (19.1%)	128 (16.24%)	623
Vehicle Same Direction	670 (25.86%)	176 (22.34%)	846
Manoeuvring	104 (4.01%)	26 (3.30%)	130
Overtaking	56 (2.16%)	22 (2.79%)	78
On Path	83 (3.20%)	30 (3.81%)	113
Off Path on Straight	397 (15.32%)	159 (20.18%)	556
Off Path on Curve	232 (8.95%)	101 (12.82%)	333
Passenger and Miscellaneous	20 (0.77%)	11 (1.40%)	31
Total	**2591 (100%)**	**788 (100%)**	**3379**

Figure 5.1 **Percentage of Crashes in Each DCA Group by ABS Brake Presence: Victoria and Queensland**

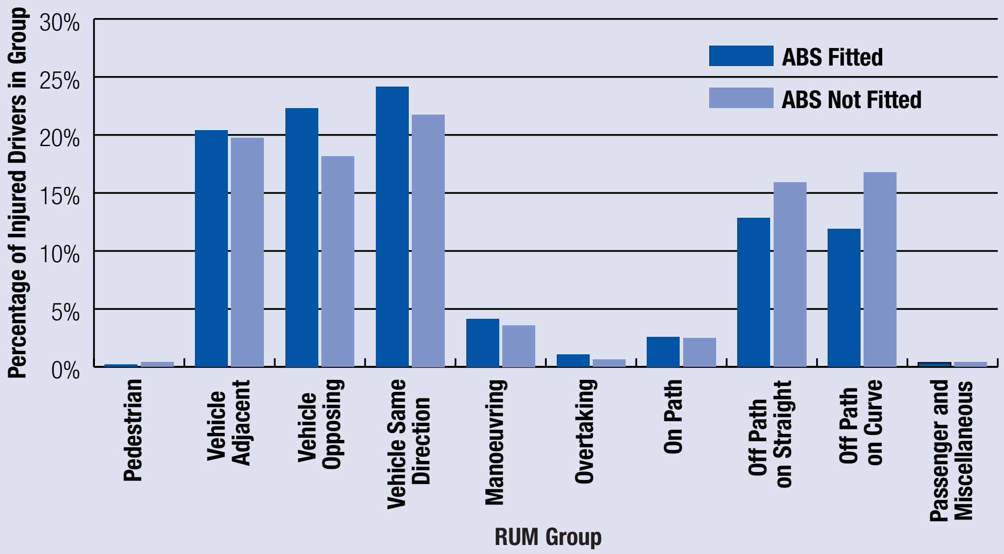


involvement where the driver is injured, ABS equipped vehicles are less likely to crash with another vehicle, particularly in adjacent and opposing direction crashes, but more likely to run off the road on either curves or straight sections than a vehicle without ABS.

Table 5.4 **ABS Presence by RUM Crash Group: New South Wales**

RUM Group	ABS Not Fitted	ABS Fitted	Total
Pedestrian	5 (0.21%)	4 (0.42%)	9
Vehicles Adjacent	495 (20.39%)	186 (19.75%)	681
Vehicles Opposing	542 (22.32%)	171 (18.15%)	713
Vehicles Same	586 (24.14%)	205 (21.76%)	791
Manoeuvring	101 (4.16%)	34 (3.6%)	135
Overtaking	26 (1.07%)	6 (0.64%)	32
On Path	63 (2.59%)	24 (2.5%)	87
Off Path on Straight	312 (12.85%)	150 (15.9%)	462
Off Path On Curve	289 (11.90%)	158 (16.77%)	447
Passenger and Miscellaneous	9 (0.37%)	4 (0.42%)	13
Total	**2428 (100%)**	**942 (100%)**	**3370**

Figure 5.2 **Percentage of Crashes in Each RUM Group by ABS Brake Presence: New South Wales**



5.2.2. Estimation of Absolute Risk of Crash Involvement

As discussed in Section 4.3.2, to estimate the absolute risk of crash involvement, it is necessary to obtain some measure of exposure. As there is a lack of sufficiently detailed exposure information available, side impact crashes, where the focus vehicle is impacted in the side by another vehicle, have been selected for use as an induced exposure measure. These crashes have been selected as it is believed that the frequency of this crash type is unaffected by the presence or absence of ABS in the vehicle. The validity of this assumption is significant for the interpretation of the results. If side impact crashes are affected by ABS fitment, any deviation from unity of the ratio R (defined in Section 4.3.2) cannot be interpreted as the change in absolute crash risk associated with ABS presence. It is believed that the incidence of side impacts will not be affected by ABS brake presence, as this impact direction is perpendicular to the direction of motion of the focus vehicle that can be altered by braking. Further, it is noted that side impact crashes have been used by Evans (1998) as an induced exposure measure in an evaluation of changes in the absolute risk of crash involvement associated with ABS vehicles.

Side impact crashes used in the analysis were selected based on the impact direction for crashes occurring in Victoria and Queensland. As impact direction was not available for crash involved vehicles in NSW, the impact type codes were used to identify side impact crashes in that state. This approach does not indicate whether the vehicle under examination is the vehicle struck in the side or the striking vehicle. However, a preliminary analysis of vehicles involved in side impact crashes in all three states indicates that the proportion of those vehicles fitted with ABS is similar across the states. It is therefore assumed in the analysis that the majority of vehicles in NSW coded as being involved in a side impact crash were the vehicle struck and not the striking vehicle.

Given the difference between the crash reporting requirements in Victoria and the other two states, only those crashes in which a driver was injured have been considered in the analysis. This eliminates any bias caused by the under reporting of uninjured drivers in Victoria where it is mandatory to report to the police only those crashes involving injury. Further, the analysis by

Table 5.5 Estimation of Absolute Crash Risk for ABS equipped vehicles in Victoria and Queensland

			90% Confidence Limits		95% Confidence Limits	
Crash Type of Interest	**R**	**ΔRisk Odds (%)***	**Lower Limit**	**Upper Limit**	**Lower Limit**	**Upper Limit**
Pedestrian	0.77	22.67	-138.15	74.89	-633.49	91.85
Vehicles Adjacent	0.78	21.80	8.48	33.18	-7.11	42.90
Vehicles Opposing	0.80	20.02	6.25	31.76	-9.88	41.78
Vehicles Same	0.81	18.75	5.58	30.08	-9.72	39.83
Manoeuvring	0.77	22.67	0.52	39.89	-27.98	53.28
Overtaking	1.22	-21.51	-60.86	8.21	-112.95	30.67
On Path	1.12	-11.80	-43.05	12.63	-83.04	31.72
Off Path on Straight	1.24	-23.88	-44.73	-6.03	-69.08	9.24
Off Path On Curve	1.35	-34.65	-59.93	-13.37	-89.96	4.55
Passenger and Miscellaneous	1.70	-70.12	-152.60	-14.56	-275.09	22.85

** Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS.*
The shaded regions identify statistically significant results.

individual crash type was not possible due to small data quantities in the defined cells. As for the analysis above, crash types were aggregated into the 10 broader crash type groupings for analysis based on the first digit of the RUM code and first two digits of the DCA code.

The analysis of Victorian and Queensland data (coded by DCA) is presented in Table 5.5 below. The analysis could not identify any significant changes in the odds related to ABS presence. However, when testing at the 10 percent level, significant changes in the odds related to ABS presence were identified. In particular, the absolute risk of being involved in crashes involving vehicles colliding from adjacent, the same or opposing directions and manoeuvring crashes is estimated to be lower for ABS equipped vehicles than for non-ABS equipped vehicles. In contrast, the risk of involvement in crashes of the accident classifications of 'vehicle leaving a straight section of carriageway' or 'curved section of carriageway' and 'passenger and miscellaneous crashes' is higher for ABS-equipped vehicles than for non-ABS equipped vehicles. The statistically significant estimates of the change in odds of particular crash types associated with ABS fitment, for those crash types with reduced odds, and range from 19% for vehicles from the same direction to 23% for manoeuvring crashes. Off path on straight and on curve crashes showed a statistically significant increase in odds associated with ABS presence at the 10 percent level of significance of 24 and 35% respectively.

In contrast to the Victorian data some significant results were obtained from the analysis of the NSW data when testing at the five percent level of significance. Vehicles leaving a straight section of carriageway showed a statistically significant increase in odds associated with ABS presence of 33.49%. Similarly, vehicles leaving a curved section of carriageway showed a statistically significant increase in odds associated with ABS presence of 51.8%. At the ten percent level, ABS was associated with a change in the risk of crash involvement for vehicles involved in collisions with pedestrians and vehicles from opposing directions. ABS was associated with an increased risk of pedestrian crash involvement but a lower risk of involvement with vehicles from opposing directions. The results are presented in Table 5.6.

The differing results obtained from the analysis of the data from different states may in part be due to the difficulty of identifying side impact crashes in the NSW data. As mentioned above, the NSW

Table 5.6 Estimation of Absolute Crash Risk for ABS equipped vehicles in NSW

			90% Confidence Limits		95% Confidence Limits	
Crash Type of Interest	**R**	**ΔRisk Odds (%)***	**Lower Limit**	**Upper Limit**	**Lower Limit**	**Upper Limit**
Pedestrian	2.22	-122.13	-336.79	-12.96	-758.89	42.55
Vehicles Adjacent	1.04	-4.33	-17.75	7.55	-32.89	18.09
Vehicles Opposing	0.88	12.40	1.01	22.47	-11.85	31.39
Vehicles Same	0.97	2.87	-9.25	13.64	-22.88	23.22
Manoeuvring	0.93	6.53	-15.98	24.67	-43.90	39.29
Overtaking	0.64	35.92	-1.58	59.58	-61.05	74.51
On Path	1.06	-5.78	-36.43	17.99	-75.97	36.42
Off Path on Straight	1.33	-33.49	-52.14	-17.12	-73.40	-2.76
Off Path On Curve	1.52	-51.80	-72.96	-33.23	-97.06	-16.93
Passenger and Miscellaneous	1.23	-23.40	-126.42	32.74	-315.42	63.34

** Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS. The shaded regions identify statistically significant results.*

data do not provide information concerning the impact direction in a crash and it was necessary to use impact type codes to identify side impact crashes. It is possible that not all vehicles coded as involved in side impact crashes were the vehicle being struck and this may account for part of the discrepancy between the two sets of analysis.

Run-off-the-road Crashes

As some earlier evaluations of ABS effectiveness have found evidence of an increased risk of involvement in run-off-the-road crashes associated with ABS, crashes of this nature were identified individually using all available data. This enabled analysis of the absolute risk of crash involvement for ABS vehicles involved in run-off-the-road crashes using data from all three states. The results are presented in Table 5.7.

Table 5.7 Estimation of Absolute Crash Risk for ABS Equipped Vehicles in Run-Off-the-Road Crashes

Crash Type of Interest	R	∆Risk Odds (%)*	95% Confidence Limits: Lower Limit	95% Confidence Limits: Upper Limit
Run-off-the-road	1.35	-35.38	-13.55	-61.41

** Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS.*

It is concluded that, the presence of ABS in a vehicle is associated with a 35% increase in the absolute risk of involvement in a run-off-the-road crash. This result is significant at the 5% level of significance. That is, it is 95% certain that the true increase in the absolute risk of involvement in a run-off-the-road crash associated with ABS lies between 14 % and 61%.

Vehicle-to-Vehicle Crashes

Hertz (1996) identified a decrease in the absolute risk of crash involvement associated with ABS fitment for vehicle-to-vehicle crashes. A combined analysis of these crash types was therefore conducted separately on both data sets. Vehicle-to-vehicle crashes were defined to include crashes involving vehicles from adjacent, opposing and the same direction and manoeuvring, overtaking and on path crashes. The results are presented in Table 5.8.

The results from the analysis of Victorian and Queensland vehicle-to-vehicle crashes indicate with 90% confidence that there is an estimated 18% decrease in the risk of involvement in this crash type associated with the presence of ABS. No such evidence could be found in the analysis of crashes occurring in NSW at either the five or ten percent level of significance. However, the point estimates of the change in risk odds are consistent with those from the Victorian and Queensland analysis.

Table 5.8 Estimation of Absolute Crash Risk for ABS Equipped Vehicles in Vehicle-to-Vehicle Crashes

Crash Type of Interest	R	∆Risk Odds (%)*	90% Confidence Limits: Lower Limit	90% Confidence Limits: Upper Limit	95% Confidence Limits: Lower Limit	95% Confidence Limits: Upper Limit
Vehicle-to-Vehicle (DCA)	0.82	17.65	5.88	27.94	-7.57	36.95
Vehicle-to-Vehicle (RUM)	0.96	4.13	-5.62	12.98	-16.37	21.01

** Negative values indicate an estimated increase in the absolute risk of crash involvement associated with ABS. The shaded region identifies a statistically significant result.*

6. Discussion & Conclusions

This study has attempted to quantify the effectiveness of ABS in terms of both primary and secondary safety. The requirement to examine only vehicle models where ABS is an option and not fitted as standard, has led to a limited availability of data. As a result, few of the estimates of the effect of ABS with respect to its secondary safety effects have achieved statistical significance. Indeed, it cannot be concluded that ABS brakes have any significant effect on secondary safety through reduction in impact severity. Nevertheless, a number of the results are worthy of discussion, particularly in relation to primary safety effects of the feature and the results of other studies examining the effectiveness of ABS.

The US Insurance Institute for Highway Safety (IIHS) has conducted several studies aiming to determine if cars equipped with ABS are involved in more or fewer fatal accidents. A 1996 study (Hertz et al, 1996) found that vehicles equipped with ABS were, overall, no less likely to be involved in fatal accidents than vehicles without. It found that cars with ABS were less likely to be involved in crashes fatal to the occupants of other cars but were more likely to be involved in crashes fatal to the occupants of the ABS-equipped car, especially in single-vehicle crashes. There was much speculation about the reasons for this, including incorrect use of the ABS by the driver pumping the brakes or by releasing the brakes when they feel the system pulsing, leading to increased braking distance. Alternatively, it has been suggested that the retention of steering control during a panic stop may increase the likelihood of run-off-the-road crashes. A more recent study (Farmer, 2001) indicates that the crash rates for ABS-equipped cars are reducing, but there is still no conclusive evidence to show that ABS improves overall safety.

Results from this study suggested that ABS might have some benefits in reducing driver injury severity in some specific vehicle models. Although none of the results were statistically significant, four out of seven vehicle models assessed showed an estimated reduction in injury severity associated with ABS presence. It was not possible to examine fatalities in this study so it is not clear whether the results from this study are consistent with others with respect to injury effects. An analysis of injury risk given crash involvement, shows that the injury risk associated with ABS is estimated to increase in seven of the eleven vehicles evaluated. However, none of these estimates were statistically significant. Further analysis, based on larger quantities of data would be required to confirm this result. Overall, this study cannot show statistically significant changes in secondary safety associated with ABS brakes.

An analysis of changes in crash type distribution associated with ABS in this study was consistent with findings by Hertz et al. (1996). The distribution of crash involvement by crash type for ABS equipped vehicles was statistically significantly different from the distribution of crash involvement by crash type for non-ABS-equipped vehicles. In particular in all three states, ABS equipped vehicles were found to be involved in fewer crashes with vehicles from adjacent, opposing or the same direction proportionately compared to non-ABS equipped vehicles. In contrast the proportion of ABS vehicles involved in run-off-the-road type crashes (i.e. 'off path on straight' and 'off path on curve') was greater than for non-ABS equipped vehicles. It is noted, however, that the results looking only at crash distribution do not necessarily measure changes in absolute crash risk.

Estimates of changes in absolute crash risk by crash type associated with ABS brakes were obtained using side impact crashes as a measure of induced exposure. Statistically significant results were obtained for a number of crash types. Most significantly, the analysis of the absolute risk of crash involvement for ABS-equipped vehicles was estimated to be approximately 35% greater than for non-ABS equipped vehicles in run-off-the-road crashes. Again, a re-analysis of this question using a larger data set would be likely to decrease the width of the confidence limits attached to the estimates. Analysis of the Victorian and Queensland data also identified an estimated 18% decrease in the absolute risk of vehicle-to-vehicle crash involvement for ABS-equipped. This result is consistent with that identified by Hertz (1996) in a study of the effectiveness of ABS braking systems.

6.1. General Issues and Further Study

The analysis of greater quantities of crash data than were available in this study would allow more definitive conclusions on the effectiveness of ABS to be drawn. Obtaining large data files for analyses such as presented in this report can be difficult but could be made easier. Obtaining information from vehicle manufacturers on vehicle specifications in terms of safety features fitted was difficult. The co-operation of those manufacturers who contributed data to the project was greatly appreciated. However, there were many more who did not participate even though invited and assured of data security and that results for specific vehicle models would not be identified. Some local manufacturers had problems obtaining build information for their imported model lines. Studies in the USA of this type are far less problematic with respect to examination of airbags as the Federal Motor Vehicle Safety Standards mandate that information about vehicle restraint systems is included in the Vehicle Identification Number. It is understood that a least one Australian manufacturer has adopted the FMVSS format for the VIN of a recent model release. It would be useful if all vehicles sold in Australia used this format, but also included information on ABS fitment. The need to control for overall vehicle safety effects in the analysis meant sufficient data had to be obtained for each vehicle model both with and without ABS for it to be included in the analysis. Because the Australian vehicle market is dominated in sales by relatively few vehicle models, this translated into only a few vehicle models having sufficient data to be included in the analysis in each case. Using two analysis methods to analyse secondary safety effects was an attempt to make the best use of the available data. The Poisson regression analysis made the best use of the data whilst the logistic method was used to test the assumptions about balance in the design.

A further possibility for this type of study is the use of more specialised data sources. In the USA, many successful studies have been carried out on the National Accident Sampling System and Fatal Accident Reporting System data. Detailed vehicle crash inspection data is also collected in Australia and includes information on vehicle damage and driver injury on a number of scales including the Abbreviated Injury Scale, Injury Severity Score and Harm. Use of these data have been successful in estimating driver airbag effects (Barnes et al., 2001) and may be useful for examining other safety features. These data are, however, very limited in the number of cases available and sampling issues must be carefully considered in any study design. Injury insurance claims data may also represent another data source with potential for providing specific injury data. Presently, however, this is not generally available in a consolidated form outside of Victoria.

6.2. Conclusions

This study has attempted to assess the effectiveness of ABS in reducing vehicle occupant injury risk and injury severity through the analysis of real crash outcomes described in mass crash data. Further, effects of ABS were also measured in terms of their effect on crash type distributions and the absolute risk of crash involvement. The opportunity to carry out this research was presented by the fact that ABS is available as optional equipment on many Australian vehicles. Consequently, the effectiveness of ABS could be examined by comparing injury outcomes in a vehicle model with and without ABS, providing a control for the inherent difference in absolute safety between vehicles.

Sufficient crash data were obtained to consider the primary and secondary safety effects of ABS. Analysis was unable to show statistically significant effects of ABS brakes on injury risk or injury severity given crash involvement. However, results of the analyses of changes in crash type distributions associated with ABS were consistent with other studies. ABS equipped vehicles were found to have a smaller proportion of crashes with other vehicles and a greater proportion of run-off-road crashes than vehicles without ABS. The difference in crash type distribution between vehicles with and without ABS was highly statistically significant. Further analysis examining the absolute risk of crash involvement, using induced exposure methods, confirmed earlier results suggesting that there is an increase in the absolute risk of involvement in run-off-the-road crashes associated with ABS and a decrease in the risk of vehicle-to-vehicle crashes. Increases and reductions in the absolute risk of crash involvement associated with ABS for other crash types were also identified and found to be significant.

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8. Appendices

8.1. Assumptions and Qualifications

The results and conclusions presented in this report are based on a number of assumptions and warrant a number of qualifications that should be noted. These are listed in the following sections.

8.1.1. Assumptions

It has been assumed that:

- TAC claims records and NSW and Queensland Police crash reports accurately recorded driver injury, hospitalisation and death.
- There was no bias in the merging of TAC claims and Victorian Police crash reports related to the model of car and factors affecting the severity of the crash.
- Crashed vehicle registration numbers were recorded accurately on Police crash reports and that they correctly identified the crashed vehicles in the Victorian, NSW and Queensland vehicle registers.
- Crashed vehicle identification numbers were recorded accurately in the various State vehicle registers
- The form of the logistic models used to relate injury risk and injury severity with the available factors influencing these outcomes (including the car models) was correct.
- Vehicle safety features provided by or determined from manufacturer provided data was accurate.

8.1.2. Qualifications

The results and conclusions warrant at least the following qualifications:

- Research presented in this report has assessed the effectiveness of ABS based on a number of defined measures and hypotheses. It is possible that the real benefits of ABS brakes on safety have not been reflected in the measures chosen.
- Estimates of overall benefits of ABS have been established from sample of vehicle models not chosen at random. It is possible that the estimates of overall effectiveness do not reflect the real average benefit of ABS examined in the total Australian vehicle fleet.

8.2. Data

Table A1. Driver injury severity by ABS presence and vehicle model

	ABS Not Fitted			ABS Fitted			
	Injury Severity			Injury Severity			
Vehicle Model	Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	Total
A	7	1	8	1		1	9
AA	407	105	512	15	3	18	530
AAA				15	2	17	17
BBB	7	3	10	14	2	16	26
CCC				1		1	1
D	74	24	98				98
DDD				3		3	3
EEE				1		1	1
F	456	147	603	341	123	464	1067
GG	136	33	169				169
H	25	17	42				42
HH	11	5	16	5		5	21
I	33	11	44	1	2	3	47
J	365	117	482				482
JJ	14	4	18	6	1	7	25
K				6	3	9	9
KK		1	1	9	3	12	13
L	622	210	832	375	122	497	1329
LL	7	3	10	21	17	38	48
MM				1		1	1
NN	6	1	7	3		3	10
O	8	5	13	13	9	22	35
P	2	1	3				3
PP	157	49	206	5		5	211
Q	529	144	673	425	114	539	1212
QQ	4		4				4
R	46	29	75				75
RR	492	141	633	45	12	57	690
S				1	1	2	2
SS	10	2	12	4	2	6	18
TT	8	1	9	1		1	10
UU	50	11	61	1		1	62
V	2		2				2
VV	44	11	55				55
WW	128	55	183	1		1	184
X	122	42	164				164
XX	10	4	14	1		1	15
Y	33	12	45				45
YY	7	3	10				10
Z	5	1	6				6
ZZ	1		1				1
Total	**3828**	**1193**	**5021**	**1315**	**416**	**1731**	**6752**

Table A2.	Driver injury risk by ABS presence and vehicle model						
	ABS Not Fitted			ABS Fitted			
Vehicle Model	**Not Injured**	**Injured**	**Total**	**Not Injured**	**Injured**	**Total**	**Total**
A	23	8	31	7	1	8	39
AA	2457	350	2807	110	9	119	2926
AAA				127	15	142	142
BBB	55	10	65	72	15	87	152
CCC				7	1	8	8
D	398	74	472				472
DDD				5	3	8	8
E	1		1				1
EEE				22	1	23	23
F	3510	506	4016	2632	391	3023	7039
GG				1		1	1
GG	809	133	942	2		2	944
H	224	34	258	2		2	260
HH	91	11	102	29	4	33	135
I	198	34	232	26	1	27	259
II				13		13	13
J	1349	414	1763				1763
JJ	146	12	158	83	2	85	243
K				29	7	36	36
KK	17		17	107	10	117	134
L	4478	718	5196	2585	413	2998	8194
LL	95	8	103	162	25	187	290
M	6		6	1		1	7
MM				7	1	8	8
NN	49	4	53	23	3	26	79
O	106	11	117	90	17	107	224
P	6	3	9				9
PP	828	156	984	27	2	29	1013
Q	3649	529	4178	2838	411	3249	7427
QQ	12	4	16				16
R	637	75	712	1		1	713
RR	3368	483	3851	274	38	312	4163
S	17		17	9	2	11	28
SS	90	10	100	21	5	26	126
T				1		1	1
TT	37	6	43	2	1	3	46
UU	224	44	268	1	1	2	270
V	3		3				3
VV	374	48	422	2		2	424
WW	926	151	1077	1		1	1078
X				2		2	2
XX	17	5	22				22
Y	185	27	212				212
YY	55	10	65				65
Z	92	5	97				97
ZZ	2	1	3				3
Total	**24534**	**3884**	**28418**	**9321**	**1379**	**10700**	**39118**

Table A3. Driver injury severity by crash DCA and ABS presence

Definition for Classifying Accidents (DCA)	DCA No.	ABS Not Fitted: Injury Severity: Minor Injury	ABS Not Fitted: Injury Severity: Severe Injury	ABS Not Fitted: Total	ABS Fitted: Injury Severity: Minor Injury	ABS Fitted: Injury Severity: Severe Injury	ABS Fitted: Total	Total
Ped near side. ped hit by vehicle from the right	100	1		1				1
Far side. ped hit by vehicle from the left	102	2		2				2
Any manoeuvre involving ped not included in DCAs 100-108	109	1		1	1		1	2
Cross traffic(intersections only)	110	246	68	314	58	21	79	393
Right far (intersections only)	111	25	1	26	3		3	29
Left far (intersections only)	112	4	5	9				9
Right near (intersections only)	113	123	37	160	32	11	43	203
Two right turning (intersections only)	114	1	1	2	2		2	4
Right/left far (intersections only)	115	1		1				1
Left near (intersections only)	116	14	3	17	5	1	6	23
Two left turning (intersections only)	118	1		1				1
Other adjacent (intersections only)	119				1		1	1
Head on (not overtaking)	120	105	95	200	41	21	62	262
Right through	121	231	60	291	48	15	63	354
Right/left. one veh turning right the other left	123	2		2				2
Other opposing manoeuvres not included in DCAs 120-125	129	2		2	3		3	5
Rear end(vehicles in same lane)	130	377	39	416	106	11	117	533
Left rear	131	56	3	59	11		11	70
Right rear	132	97	10	107	28	2	30	137
Lane side swipe (vehicles in parallel lanes)	133	9	4	13	4	1	5	18
Lane change right (not overtaking)	134	13	5	18	3		3	21
Lane change left (not overtaking)	135	15	4	19	3		3	22
Right turn sideswipe	136	25	5	30	5	1	6	36

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Table A3. Continued

Definition for Classifying Accidents (DCA)	DCA No.	ABS Not Fitted			ABS Fitted			Total
		Injury Severity			Injury Severity			
		Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	Total
Left turn sideswipe	137	3	2	5				5
Other same direction-manoeuvres not included in DCAs 130-137	139	2	1	3	1		1	4
U turn	140	27	9	36	10	3	13	49
U turn into fixed object/parked vehicle	141	1		1				1
Leaving parking	142	10		10		1	1	11
Entering parking	143	1		1				1
Reversing in stream of traffic	145	4		4	1		1	5
Reversing into fixed object/parked vehicle	146	1		1				1
Vehicle strikes another veh while emerging from driveway	147	45	5	50	8	1	9	59
Other manoeuvring not included in DCAs 140-148	149	1		1	2		2	3
Head on (overtaking)	150	12	6	18	2	1	3	21
Out of control (overtaking)	151	13	10	23	9	3	12	35
Pulling out (overtaking)	152	7	2	9	3	1	4	13
Cutting in (overtaking)	153					1	1	1
Pulling out -rear end	154	4		4				4
Other overtaking manoeuvres not included in DCAs 150-154	159	2		2	2		2	4
Vehicle collides with vehicle parked on left of road	160	21	8	29	7	3	10	39
Double parked	161		1	1				1
Accident or broken down	162	8		8	2		2	10
Permanent obstruction on carriageway	164	3		3		1	1	4
Temporary roadworks	165	4		4				4
Struck object on carriageway	166	9	6	15	3	2	5	20
Struck animal	167	9	7	16	8	2	10	26

Continued next page

Table A3. Continued

Definition for Classifying Accidents (DCA)	DCA No.	ABS Not Fitted			ABS Fitted			Total
		Injury Severity			Injury Severity			
		Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	
Other on path	169	6	1	7	1	1	2	9
Off carriageway to left	170	27	13	40	9	2	11	51
Left off carriageway into object/parked vehicle	171	86	67	153	42	27	69	222
Off carriageway to right	172	12	16	28	6	6	12	40
Right off carriageway into object/parked vehicle	173	73	55	128	26	22	48	176
Out of control on carriageway (on straight)	174	13	9	22	6	4	10	32
Off end of road/t-intersection	175		1	1				1
Other accidents-off straight not included in DCA+A67s 170-175	179	10	15	25	7	2	9	34
Off carriageway on right bend	180	19	8	27	6	5	11	38
Off right bend into object/parked vehicle	181	56	26	82	28	19	47	129
Off carriageway on left bend	182	10	5	15	3	3	6	21
Off left bend into object/parked vehicle	183	38	24	62	15	9	24	86
Out of control on carriageway (on bend)	184	13	9	22		5	5	27
Other accidents on curve not included in DCAs 180-184	189	16	8	24	5	3	8	32
Fell in/from vehicle	190	3	2	5	2		2	7
Load or missile struck vehicle	191	1	2	3	2	3	5	8
Struck train	192	4	2	6	2		2	8
Struck railway crossing furniture	193	2		2				2
Parked car run away	194		1	1	1	1	2	3
Other accidents not classifiable elsewhere	198	1	2	3				3
Total		**1928**	**663**	**2591**	**573**	**215**	**788**	**3379**

Table A3.1. Chi-squared analysis of crash distribution for ABS and non-ABS equipped vehicles: Victoria and Queensland

DCA		Not Fitted	Fitted	Total
Pedestrian	Count	4	1	5
	Expected Count	3.833975	1.166025	5
Vehicle Adjacent	Count	530	134	664
	Expected Count	509.1518	154.8482	664
Vehicle Opposing	Count	495	128	623
	Expected Count	477.7132	145.2868	623
Vehicle Same Direction	Count	670	176	846
	Expected Count	648.7085	197.2915	846
Manoeuvring	Count	104	26	130
	Expected Count	99.68334	30.31666	130
Overtaking	Count	56	22	78
	Expected Count	59.81	18.19	78
On Path	Count	83	30	113
	Expected Count	86.64782	26.35218	113
Off Path on Straight	Count	397	159	556
	Expected Count	426.338	129.662	556
Off Path on Curve	Count	232	101	333
	Expected Count	255.3427	77.6573	333
Passenger and Miscellaneous	Count	20	11	31
	Expected Count	23.77064	7.229358	31
Total	**Count**	**2591**	**788**	**3379**
	Expected Count	**2591**	**788**	**3379**

Chi-square Tests

	Value	Degrees of Freedom	Asymptotic Significance (2 Sided)
Pearson Chi-Square	32.24342	9	0.000181
Likelihood Ratio	31.30462	9	0.000262
Linear-by-Linear Association	29.1924	1	6.55E-08
N of Valid Cases	3379		

Note: 2 cells (10%) have expected count less than 5. The minimum expected count is 1.17.

Table A4. Driver injury severity by RUM Code and ABS presence

Road User Movement (RUM)	RUM Code	ABS Not Fitted			ABS Fitted			Total
		Injury Risk			Injury Risk			
		Not Injured	Injured	Total	Not Injured	Injured	Total	
Ped nearside	0	3		3				3
Ped emerging	1	1		1				1
Ped far side	2				2		2	2
Ped playing	3	1		1	1		1	2
Ped on footpath	6				1		1	1
Cross traffic	10	272	54	326	111	15	126	452
Right far	11	15	4	19	4	1	5	24
Left far	12	4		4	2		2	6
Right near	13	102	31	133	41	9	50	183
2 right turning	14	1		1				1
Left near	16	8	3	11	3		3	14
Other adjacent	19	1		1				1
Head on	20	163	89	252	42	33	75	327
Right through	21	235	55	290	80	16	96	386
Rear end	30	364	49	413	139	14	153	566
Left rear	31	18	3	21	1		1	22
Right rear	32	76	13	89	25	1	26	115
Lane sideswipe	33	10	2	12	3	3	6	18
Lane change right	34	18	4	22	8	2	10	32
Lane change left	35	11	5	16	4		4	20
Right turn sideswipe	36	4	1	5	3		3	8
Left turn sideswipe	37	5	1	6	1		1	7
Other same direction	39	1	1	2	1		1	3
U turn	40	40	8	48	17	1	18	66

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Table A4. Continued

Road User Movement (RUM)	RUM Code	ABS Not Fitted			ABS Fitted			Total
		Injury Risk			Injury Risk			
		Not Injured	Injured	Total	Not Injured	Injured	Total	
U turn into object	41	3		3				3
Leaving parking	42	11	2	13	3		3	16
Reversing	45	1	1	2	5	1	6	8
Reversing into obj	46	4		4	2		2	6
Emerging from drive	47	23	4	27	2		2	29
Other manoeuvring	49	2	2	4	2	1	3	7
Head on (overtake)	50	4	5	9	2		2	11
Out of control otake	51	3	1	4		1	1	5
Overtake turning	53	9	1	10	1	1	2	12
Cutting in	54	1		1	1		1	2
Pulling out rear end	55		1	1				1
Other overtaking	59	1		1				1
Parked	60	21	5	26	12		12	38
Double parked	61	1		1	1		1	2
Accident	62	11	2	13	2		2	15
Vehicle door	63	3		3				3
Perm obstruction	64	1		1				1
Temp road works	65	1		1		1	1	2
Object on road	66	2		2	1		1	3
Struck animal	67	10	3	13	5	2	7	20
Other on path	69	3		3				3
Off road to left	70	17	9	26	5	3	8	34
Off road left => obj	71	126	47	173	48	26	74	247
Off road to right	72	14	8	22	8	2	10	32

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Table A4. Continued

Road User Movement (RUM)	RUM Code	ABS Not Fitted			ABS Fitted			Total
		Injury Risk			Injury Risk			
		Not Injured	Injured	Total	Not Injured	Injured	Total	
Off road right => obj	73	62	21	83	32	16	48	131
On road-out of cont.	74	4	1	5	4	1	5	10
Off end of road	75	1	2	3	4	1	5	8
Off left/right bend	80	14	8	22	8	2	10	32
Off left/right bnd=>obj	81	76	33	109	38	23	61	170
Off right/right bend	82	6	3	9	1	3	4	13
Off right/right bnd=>obj	83	18	17	35	30	7	37	72
Off right/left bend	84	5	5	10	2	2	4	14
Off right/left bnd=>obj	85	42	8	50	17	5	22	72
Off left/left bend	86	5	3	8	1	1	2	10
Off left/left bnd=>obj	87	20	9	29	11	4	15	44
Out of control on bend	88	12	5	17	3		3	20
Object struck veh	91	2	1	3	1		1	4
Struck train	92	2		2		2	2	4
Parked veh runaway=>obj	93	1		1	1		1	2
Parked veh runaway=>veh	94	1		1				1
Alighting/boarding	95	1		1				1
Other	98	1		1				1
Total		**1898**	**530**	**2428**	**742**	**200**	**942**	**3370**

Table A4.1. Chi-squared analysis of crash distribution for ABS and non-ABS equipped vehicles: NSW

DCA		Not Fitted	Fitted	Total
Pedestrian	Count	5	4	9
	Expected Count	6.484273	2.515727	9
Vehicle Adjacent	Count	495	186	681
	Expected Count	490.6433	190.3567	681
Vehicle Opposing	Count	542	171	713
	Expected Count	513.6985	199.3015	713
Vehicle Same Direction	Count	586	205	791
	Expected Count	569.8955	221.1045	791
Manoeuvring	Count	101	34	135
	Expected Count	97.26409	37.73591	135
Overtaking	Count	26	6	32
	Expected Count	23.05519	8.944807	32
On Path	Count	63	24	87
	Expected Count	62.68131	24.31869	87
Off Path on Straight	Count	312	150	462
	Expected Count	332.8593	129.1407	462
Off Path on Curve	Count	289	158	447
	Expected Count	322.0522	124.9478	447
Passenger and Miscellaneous	Count	9	4	13
	Expected Count	9.366172	3.633828	13
Total	**Count**	**2428**	**942**	**3370**
	Expected Count	**2428**	**942**	**3370**

Chi-square Tests

	Value	Degrees of Freedom	Asymptotic Significance (2 Sided)
Pearson Chi-Square	27.28796	9	0.001253
Likelihood Ratio	26.80922	9	0.001504
Linear-by-Linear Association	17.0208	1	3.7E-05
N of Valid Cases	3370		

Note: 2 cells (10%) have expected count less than 5. The minimum expected count is 2.52

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