Centre for
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Potential benefits of forward collision avoidance technology

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Executive summary

Main points

- The simulation study detailed in this report predicts significant crash reductions with the introduction of forward collision avoidance technology (FCAT) systems.
- Between 20 and 40 per cent of all fatal crashes and between 30 and 50 per cent of all injury crashes might be prevented with FCAT systems (note that these figures do not account for any unreliability in operation).
- The estimates are consistent with previous studies that have suggested reductions of up to and in excess of 40 per cent.
- The greatest estimated benefit is from a system that combines long and short range sensing.
- Systems with expansive fields of view and that are highly reactive have a greater theoretical effect, but may suffer from the problem of false-positive responses.
- A narrow field of view that reduces the chance of false-positive interventions appears to provide substantial benefit; the results of such a system were comparable to a system with a wide field of view.
- Estimated benefit-cost ratios (BCR) for passenger vehicles are marginal at less than one in most instances, due to high system costs and declining per-vehicle crash rates. However, a halving of system costs would see BCRs exceed one.
- Heavy vehicle BCRs are much higher: between 2.7 and 9.8.

Recommendations

- Encourage the uptake of FCAT systems by heavy vehicle operators and in passenger vehicle markets as soon as possible.
- Liaise with industry groups such as the Federal Chamber of Automotive Industries and the Truck Industry Council with a view to finding pathways for the wider-scale introduction of FCAT technologies.
- In programs such as the Australasian New Car Assessment Program (ANCAP), provide substantial credit for the installation of effective FCAT systems.
- Encourage the creation of performance standards for such systems, to ensure uniformly high effectiveness, and to provide a means of assessment by ANCAP.
- Monitoring and evaluation of systems as they are introduced, to confirm or otherwise the benefits of the systems that have been estimated via simulation in this study and similar studies.

Advanced driver assistance systems (ADAS) are likely to become increasingly available in new vehicles over coming years. ADAS typically involve arrays of sensors that provide the vehicle with information about the immediate environment surrounding the vehicle. Important applications of ADAS focus on crash avoidance or mitigation; these applications sense a potential collision and intervene in some way to warn the driver, support emergency manoeuvres or even act autonomously to prevent a collision, or at least mitigate the collision by reducing speed before the crash. Given the connection between impact speed and injury risk, these applications have the potential to drastically reduce the incidence and severity of crashes.

This report had several objectives. The first was to describe current ADAS systems that may be described as forward collision avoidance technological systems (FCAT systems), and the trials and evaluations of such systems. FCAT systems typically sense other road users or objects in the forward path of the vehicle and perform some combination of actions in response to a collision threat. Actions may include priming brake systems, warning the driver, applying gentle braking or more aggressive braking, either in concert with the driver, or autonomously.

Several field trials of FCAT systems have been conducted in the past, but either published results from the trials are few, or the numbers of vehicles in the trial were small, and hence the trials are limited in what they tell us about the potential benefits of FCAT systems. However, field trials have suggested that forward collision warning systems are generally accepted by drivers using the systems, and do not appear to have negative effects on their driving behaviour. Several field trials of FCAT systems are ongoing; in some cases results have yet to be published, and in others the results are not publically available. Nevertheless, insurance data is already beginning to show that vehicles equipped with such systems experience considerably fewer crashes and an even greater reduction in claims for injury.

The second objective of this report was to describe testing and regulatory issues around such systems. There are no current regulations or standards that specify comprehensive design and performance requirements for FCAT systems with autonomous emergency braking. Without such standards some vehicle manufacturers may be reluctant to develop and supply FCAT systems on the vehicles that they offer for sale in Australia. Similarly Australian regulators and consumer organisations such as ANCAP are unlikely to implement unique requirements for FCAT in the absence of suitable international standards. International standards could take the form of a United Nations Economic Commission for Europe (UNECE) Regulation or a Global Technical Regulation (GTR).

At this stage, the development of a UNECE Regulation or GTR for FCAT systems for light vehicles does not appear to be a stated goal, and so may be several years away. For heavy vehicles, there is currently a draft UNECE Regulation being developed, using the term Advanced Emergency Braking Systems (AEBS). Consideration of this as a national regulation for Australia, once finalised, is an action under the National Road Safety Strategy 2011-20. It is understood that once a UNECE regulation is developed for heavy vehicles, the technology for light vehicles would also be considered (Hoy S, personal communication, April 19, 2012).

In the interim, the most promising FCAT standard that could be used in Australia in the near term is the protocol being developed by a Euro NCAP working group for consumer rating purposes. Another recommendation of this report is that ANCAP give substantial credit to manufacturers who install effective FCAT systems on their vehicles, as part of vehicle assessments.

The third objective of the report was to estimate the effectiveness of FCAT systems based on Australian crash data. This involved a three-step process:

- Estimation of the average changes in crash risk brought about with the use of FCAT systems using in-depth crash data,
- Estimation of the likely rate of crash involvement of vehicles that will be built during the present decade,
- Application of the changes in risk to the rate of crash involvement to estimate the per-vehicle benefit of having an FCAT system installed.

One hundred and four crashes that occurred within 100 km of Adelaide, South Australia, were selected to represent crash configurations likely to be affected by FCAT systems. The crashes had been investigated at the scene, and in this study they were analysed using simulation methods to estimate how collision speeds would have been modified with an FCAT system. Two categories of FCAT system were considered: a short-range system and a long-range system. Five variants of each type of system were simulated. In addition a combination system was simulated.

Crash types considered were rear-end, pedestrian, head-on, intersection and a proportion of hit-fixed-object crashes. Other crash types were considered less responsive to the effects of FCAT systems.

The variations in FCAT systems were described using several parameters: the range of the forward-looking zone, the angle or width of the forward looking zone, the processing time for the system to respond to the road user or object in its path, the time-to-collision (TTC) at which the system would intervene, and the strength of the intervention (the level of braking). The FCAT simulation used information from the trajectory of vehicles in the 104 crash reconstructions to estimate what difference each system would have made to the collision speed in each case and for each FCAT system considered. Injury risk curves were used to estimate changes in fatal and injury crash risk in each case.

The reductions in risk were weighted according to the rate of crash involvement of vehicles. This rate was estimated for vehicles that will be built in the years 2010 to 2020, based on the patterns of, and trends in crash types in New South Wales crash data for years 1999-2009.

The overall reductions in risk produced by the various FCAT systems were substantial (these are detailed in Table I below). Up to 40 per cent of fatal crashes and 50 per cent of injury crashes might be prevented with a comprehensive and effective system. These estimates will need to be attenuated by expected overall reliability of actual systems. Note that any line-of-sight limitation in each crash was considered in the analysis, while effects of darkness or other forms of poor visibility were not considered. Longer-range and longer time to collision algorithms with expanded fields of view produced the highest estimated reductions, but technical challenges exist for such systems: if the range of such systems is too expansive, then eliminating false-positive responses is likely to be a problem.

More conservative systems that monitor a short range directly ahead of the vehicle are also likely to have a substantial effect: system G in Table I, which examines a narrow field in front of the vehicle but intervenes with full braking after a short reaction time, would provide a substantial benefit, and is predicted to prevent almost as many fatalities as the more comprehensive system that includes long-range and short-range sensors (B + J).

Several prior estimates of FCAT effectiveness have been made through simulations similar to those reported here.

A potential obstacle to the wide-scale introduction of such systems is the system cost, which presently appears to be high, particularly relative to the per-vehicle benefit of such systems. Benefit cost ratios would appear to presently lie between 0.3 and 1.3, depending on the timing of the introduction of the system and the style of system being considered. No such obstacle exists for heavy vehicles however, given their relatively high rates of crash involvement. Heavy vehicle BCRs range from 2.7 to 9.8.

Nevertheless, encouragement should be given to passenger vehicle manufactures to install such systems, because even relatively simple short-range systems that intervene strongly may provide substantial benefits. Wide-scale introduction will, in all likelihood, reduce marginal costs. This in turn will improve the ratio of benefits to costs.

Table I
Indicative percentage reductions in crashes predicted for various types of FCAT system

System	Reduction			
	Fatal		Injury	
	Of all relevant forward collision	Of all fatal crashes	Of all relevant forward collision	Of all injury crashes
Long Range				
A: Baseline	34	23	50	36
B: Higher braking force	37	25	53	38
C: Shorter TTC	30	21	42	30
D: Longer TTC	34	23	53	38
E: Wider angle	34	24	58	42
Short Range				
F: Baseline	34	24	41	30
G: Higher braking force	40	28	48	34
H: Shorter TTC	31	21	32	23
I: Wider detection area	52	36	53	38
J: Wide angle	44	31	50	36
Combination				
B plus J	56	39	67	48

Contents

1 Introduction

The last decade has seen the advent of various intelligent driver aids that are commonly referred to as advanced driver assistance systems (ADAS). Some examples of ADAS are lane departure warning, intelligent speed adaptation, automatic parking, electronic stability control and adaptive cruise control (ACC). As these systems have matured, some that were originally developed simply to ease the driver's task have been developed to provide a safety benefit. ACC is a prime example of such a technology. ACC, originally developed to allow the driver to keep cruise control active in traffic of varying speed, has been expanded to autonomously brake the vehicle when an impending collision is detected. Such systems are generally referred to as forward collision avoidance technology (FCAT).

The aims of this project were to:

- Review trials and other evaluations of FCAT systems
- Examine the literature for estimates of FCAT effectiveness
- Report on the different technologies associated with FCAT systems
- Review current costs of FCAT systems
- Describe testing and regulatory issues around FCAT systems
- Estimate the effectiveness of FCAT systems in Australia
- Conduct a benefit-cost analysis of FCAT systems given probable crash rates of vehicles in Australia

1.1 Consultation with key stakeholders

Regulators, insurers, vehicle manufacturers, system manufacturers and vehicle safety researchers were contacted at the start of the project to obtain up-to-date information about available technologies, performance standards and effectiveness studies.

Several manufacturers provided relevant technical information about their systems in production. Manufacturers were generally unable to provide specific information on systems under development, however a few were able to provide technical performance specifications. These were used to guide the choice of system parameters in the simulation study described in Section 5.

Much of the information that was gained from these consultations has been used throughout the report. A summary of the activity surrounding FCAT systems that was reported to us is as follows:

- A Euro NCAP working group is developing an assessment protocol for autonomous emergency braking (AEB) systems as part of its consumer rating system. The group is collaborating with several other European groups that are developing test methods. The draft Euro NCAP protocols are confidential at this stage but we were provided with some details of proposed performance tests. A comprehensive overview of developments in this area is provided in Appendix A.
- Thatcham (UK) is developing a series of performance tests for AEB. These will be used by the RCAR consortium, which comprises insurance industry research organisations. There is a Thatcham representative in the Euro NCAP group.
- TRL Limited (UK) has conducted FCAT-related research for the European Commission and provided us with research reports. They also provided information about several

related European projects - UNECE, ISO, AsPeCSS and ASSESS (described in Appendix A).

- Transport Canada has developed performance tests for AEB, in consultation with the RCAR group. They are also contributing to the development of an ISO standard for assessing AEB performance.
- The US National Highway Traffic Safety Administration (NHTSA) is working on various requirements for Forward Vehicle Collision Mitigation Systems (FVCMS) and is expected to issue a notice of proposed rulemaking for a regulation later this year. US NCAP (part of NHTSA) has started listing vehicles with forward collision warning systems in its information for consumers.
- The Japanese Automotive Research Institute (JARI) is not working directly on FCAT but is participating in the development of an ISO standard.

2 Literature review

This literature review contains two distinct sections. Section 2.1 focuses on trials and field operational tests that are related to FCAT. While some of these trials have been completed and have reported results, many either did not have reported results or are ongoing. Section 2.2 focuses on literature that has attempted to estimate the effectiveness of FCAT.

2.1 FCAT related trials and field operational tests

Accident prevention systems for lorries (Netherlands, 2008)

An on-road trial involving 2,400 lorries supplied by 123 companies was conducted between 2008 and 2009 in the Netherlands by the Ministry of Transport, Public Works and Water Management (Connekt/ITS, 2009). The study lasted eight months and a total of 77 million km of driving behaviour was measured during normal daily driving on Dutch motorways.

The trial considered the effectiveness of the systems, the effect on traffic safety and traffic flow assuming significant fleet penetration, and the role of government in encouraging the use of the systems.

The trial included adaptive cruise control (ACC), lane departure warning (LDW), forward collision warning (FCW), headway monitoring and warning (HMW), directional control / roll over control (DC/ROC) and black box feedback (BBFB) technology.

The trial concluded that Dutch drivers maintain a gap of around 0.5 to 1.5 seconds when driving at a speed of 80 km/h on motorways. Since maintaining sufficient headway to the vehicle in front is a key aspect of driving, the trial findings support the following:

- ACC can reduce driver workload involved in maintaining sufficient headway distance and FCW/HMW can support this task.
- DC and ROC actively prevent the vehicle from reaching critically unstable dynamics.
- LDW helps prevent unintentional lane breaches, so long as the system does not distract the driver from other key driving tasks.
- BBFB encourages more consistent driving behaviour provided the driver has sufficient social motivation to modify their driving behaviour.

The study did not find significant safety benefits in FCW, ACC or HMW systems. However the authors note that there were several confounding factors in the study, including incomplete monitoring of when the systems were in use (drivers were able to disable the systems) and the observation that typical headways on Dutch motorways are relatively short compared with neighbouring countries. This meant that the FCW/HMW systems would be giving frequent warnings and were likely turned off.

It was recommended that, in future studies, the duration of monitoring of participants be increased, that accident data be studied to determine whether the observed low accident rate is maintained over time, to keep providing incentives to drivers who choose to use the systems and to further examine the effect the systems have on driver behaviour.

ACAS (Auto Collision Avoidance System) (US, 1996))

The three-year ACAS Program, which ended in May 1998, was funded by the Defense Advanced Research Projects Agency (DARPA) as part of the Technology Reinvestment Project (TRP) (Zador *et* *al.* 2000). The National Highway Traffic Safety Administration (NHTSA) was responsible for technical management and oversight of the program. The ACAS Program also included activities to reduce the cost and improve the manufacturability of radar components and to understand the nature of driver interactions with rear-end collision warning systems.

The ACAS program is referred to in Ference (2001) but few other details on this program have been found.

ACAS field trial (Phase 1) (US, 1999)

The 1999 ACAS program appears to be a follow on from an earlier program, also known as ACAS. The 1999 field trial involved passenger vehicles fitted with rear end collision warning and ACC systems. The field trial was focused on warning rather than intervention systems (Ference, 2001).

Partners in the ACAS field trial included Delphi Delco Electronics Systems, Delphi Chassis Systems, HRL Laboratories, the University of Michigan Transport Research Institute (UMITRI) and NHTSA. UMITRI was responsible for managing and conducting the trial and analysing the data. Program coordination and technical oversight was provided by NHTSA's Office of Advanced Safety Systems Research.

During the first phase of the trial, a prototype vehicle was developed and tested. No results or conclusions could be sourced for this trial.

ACAS FOT (Phase 2) (US, 2001)

In 2001 the second phase of the ACAS field trial commenced and lasted approximately 12 months. Eleven Buick LeSabre sedans were involved in this phase of the trial and a total of 96 volunteer drivers participated.

Two pilot test vehicles were developed, based on the prototype vehicle from phase 1 (see Ference 2001). After further testing and validation of the pilot vehicle design a total of 11 vehicles were equipped with the rear end collision warning and ACC systems. The on road component of the trial involved volunteer drivers using the vehicles on public roads over a period of several weeks. Data collected by an in-vehicle data acquisition system was analysed to provide estimates of system effectiveness and potential safety benefits of the technology.

Data collected from on-board the vehicles was supplemented by post trial questionnaires and focus group meetings to collect additional information on driver experience and user acceptance of the systems involved in the trial.

No results or conclusions could be sourced for this trial.

CAMP FCW (US Michigan, 1999)

This study is referred to by Fockenbrock and O'Harra (2009), however no project reports or other information could be identified. The study was undertaken in 1999 in Michigan, USA and involved 108 drivers undertaking emergency braking scenarios in a 1997 Ford Taurus. The study appears to have been aimed at addressing forward collision warning (FCW) timing requirements.

CAMP follow up (US Ohio)

This project followed on from the previous CAMP study and aimed to address FCW timing requirements. The project was undertaken in Ohio, USA and followed the same methodology as the previous CAMP study (Kiefer *et al.* 2003).

During the study, ‘last-second’ braking manoeuvre data, and “last-second” steering (or lane change) manoeuvre data was collected. Drivers performed these manoeuvres under different scenarios and with two different levels of intensity (normal or hard). The results of the study were used to validate the deceleration model developed in the previous CAMP FCW project (Kiefer *et al.* 2003).

IVBSS (Integrated Vehicle Based Safety Systems) (US, 2005)

This five year field trial involving NHTSA, UMITRI, Visteon, Honda and Takata as partners involved trucks and light vehicles. Forward collision warning (FCW), drifting, lane change, and curve speed warning technologies were evaluated (Sayer *et al.* 2011).

The truck field trial began in February 2009, with 20 participants that represented a sample of commercial drivers operating within a freight carrier’s fleet. This trial was completed in December 2009, after approximately 10 months of data collection on 10 commercial trucks. Two drivers did not complete the truck trial, so the final data set included only 18 commercial drivers (Nodine *et al.* 2011).

The light vehicle field trial began in April 2009 and was completed in May 2010. The light vehicle trial collected naturalistic data from 108 licensed drivers over 12 months and used 15 instrumented passenger cars. The key findings indicate that use of the integrated crash warning system resulted in improvements in lane keeping, fewer lane departures, and increased turn-signal use. Both the passenger car and commercial drivers accepted the integrated crash warning system and benefited from improved awareness of vehicles around them. No negative behavioural adaptation effects of using the integrated system were observed in either driver group (Sayer *et al.* 2011).

Drivers that participated in these field trials reported that they did not rely on the added crash-avoidance technologies, and the results of the study support this claim. The results suggested that there were no negative behaviours that developed with use of the system. Light vehicle drivers maintained a slightly higher headway with the systems installed, and there was no evidence to suggest increased risk compensation or behavioural adaptation. Drivers generally preferred systems that provided subtle feedback (such as the lane departure warning that included a haptic seat), rather than more intrusive systems such as the auditory warning used for curve speed warning and FCW (Sayer *et al.* 2011).

RDCW (Road Departure Crash Warning) (US)

This on-road field trial was conducted under a cooperative agreement between the U.S. Department of Transportation and the University of Michigan Transportation Research Institute, along with its partners, Visteon Corporation and AssistWare Technologies (UMITRI 2003, LeBlanc *et al.* 2006). The purpose of the trial was to develop, validate and field test several in-vehicle driver assistance technologies including lane departure warning, curve speed warning and lateral drift warning. Although no FCAT technology was used in the trial it is included as there is some overlap in technology and the methodology of the trial is relevant.

Seventy eight drivers participated, each driving one of 11 test vehicles equipped with the technology listed above. Analysis of data collected from the vehicles showed that lane keeping performance improved and turn signal use increased. The authors indicated that driver acceptance of the lateral drift and lane departure warning system was positive but that driver acceptance for the curve speed warning system was mixed. Measures of driver acceptance were determined from post-trial questionnaires and focus groups.

Comparative test of advanced emergency braking systems (Germany, 2011)

Undertaken by the *Allgemeiner Deutscher Automobil-Club* (ADAC) in Germany in 2011, this field trial involved track testing of FCW and autonomous braking systems using production vehicles available to the public fitted with OEM systems (ADAC, 2011). The test vehicles were:

- Volvo V60 D5 AWD Geartronic
- Mercedes CLS 350 CGI
- Audi A7 3.0 TFSI
- VW Passat Variant 2.0 TFSI DSG
- BMW 530d Automatic
- Infiniti M37S Premium

The purpose was to provide a comparative series of assessments as determined from a series of repeatable dynamic tests. The tests evaluated reduction in impact speed, effectiveness of warnings and probability of false alarms. In the tests a mock vehicle was used which the test vehicle could impact without damage to either the test vehicle or the mock vehicle. The mock vehicle was used in a stationary position, or was towed behind another vehicle depending on the test type.

The results of the evaluation showed a range of performance between the systems with the Volvo Citysafe system scoring best and the Infiniti obtaining the least favourable score.

This trial also involved assessing the impact on accident severity of the FCW systems by subjecting a Mercedes Benz C Class vehicle body to crash tests with test conditions simulating scenarios where the FCW system (Pre-Safe) is active or where the FCW system is inactive or not present.

In these tests injury measurements were lower in all measured values for the driver, front passenger and right seated rear occupant of the Pre-Safe enabled.

EuroFOT (Europe ,2008)

EuroFOT is a large scale vehicle safety technology field trial in progress in various locations across Europe. EuroFOT commenced in May 2008 and is due for completion in June 2012. There are 28 EuroFOT partners from 10 European countries including Ford, BMW, Daimler, Volvo, Audi, Man, Volkswagen, Bosch, Continental, Delphi, INRETS, TNO and Ertico (Csepinszky, 2011).

The study involves FCW, active cruise control, blind spot monitoring, lane departure warning and curve speed warning technology in over 1000 passenger cars and trucks (however not all vehicles are fitted with relevant FCAT technology). Relevant FCAT technologies are fitted to participating MAN trucks, Ford cars and Volvo cars and trucks. Naturalistic driving studies will be used to assess the technologies and will be conducted over a 12 month period.

The objectives of EuroFOT included assessing the performance and capabilities of in-vehicle systems, observing driver behaviour and experience with these systems, collecting data to further improve knowledge on the socio-economic impact of the systems on safety efficiency and driver comfort, promoting the systems publicly and fostering public acceptance of the systems.

Results from this trial are not yet available (Final results are due June 2012).

SARTRE (Europe, 2009)

Having commenced in 2009, SARTRE is a three year trial program based in Europe. The aim of SARTRE is to address the integration and development of technology necessary to implement a platooning system and to examine the human factors that are relevant in the operation of the system (Robinson *et al.*, 2010). SARTRE involves platooning (road train) technology in light vehicles (with a truck as the lead vehicle) and overlaps with FCAT technology as elements of autonomous braking, active cruise control, and FCW are present in the platooning systems (Robinson *et al.*, 2010).

Although SATRE will predominantly be conducted on closed roads and test tracks, suitable highway sections have been identified for on-road trials.

SATRE will include consideration of emergency lane change, potential side impact scenarios, emergency stop, lead vehicle mistakes (e.g. lead vehicle leaving the road, colliding with another object) and communications loss.

SARTRE partners include Ricardo UK Ltd, Applus, IDIADA, IKA, Robotiker-Tecnalia, SP Technical Research Institute of Sweden, Volvo Car Corporation and Volvo Technology. Successful SARTRE demonstrations have been conducted with platoons containing between one and four passenger cars (AutoEvolution, 2011).

Freilot Urban Freight Energy Efficiency Pilot (FREILOT) (Europe, 2009)

The Freilot trial involves 100 trucks (1000 drivers) and 11 passenger cars (96 drivers) fitted with rear end collision avoidance, RDW, ISA, ACC and LDW systems. Freilot is an on-road field trial and is being conducted in various locations across Europe. Volvo, Mercedes, IVECO, Nissan and MAN trucks are involved in the Freilot FOT (Blanco and Garcia, 2009).

No results or conclusions were available but are expected towards the end of 2012.

TeleFOT (Europe, 2008)

TeleFOT involves on-road evaluations of nomadic and aftermarket devices including FCW systems in various locations across Europe (Finland, Sweden, Germany, UK, France, Greece, Italy and Spain). Having commenced in June 2008 TeleFOT is due to run for four years. TeleFOT aims to assess the impact of functions provided by aftermarket and nomadic devices in vehicles and to raise awareness of the safety potential of these devices (TeleFOT 2012).

No results or conclusions were available and it is currently unclear as to whether the project has been concluded or terminated.

Intelligent Cruise Control Field Operational Test (US, 1997)

The Intelligent Cruise Control (ICC) field operation test involved collaboration between NHTSA and UMTRI. The main goal of the FOT was to “characterize safety and comfort issues that are fundamental to human interactions with an automatic, but driver-supervised, headway-keeping systems” (Fancher *et al.*, 1998).

A fleet of 10 passenger cars (1996 Chrysler Conchords) with infrared ranging sensors, headway-control algorithms, and driver interface units, as needed to provide adaptive cruise control (ACC) functionality, were driven by 108 volunteers for two or five weeks as their personal cars as part of an on-road trial lasting from July 1996 to September 1997.

The findings were that ACC has a high level of acceptance with drivers and that they adopt driving behaviours that will allow them to keep the system engaged for as long as possible. Some trial participants had concerns about the system such as performance in poor weather, the level of acceleration and deceleration of the system when engaging/disengaging and deceleration due to a false detection condition.

Volvo IVI FOT (US, 2001)

The Volvo Intelligent Vehicle Initiative (IVI) Field Operational Test (FOT) was a major collision warning trial focused on heavy vehicle systems. The study included evaluation of the effectiveness of FCAT systems and estimated the costs and benefits to society of the systems. All systems studied were in commercial production, or close to commercial production and were designed for use in heavy vehicles (Batelle, 2007).

The technology evaluated in the trial included Collision Warning System (CWS), Adaptive Cruise Control (ACC) and Advanced Braking System (AdvBS).

One hundred Volvo VN770 trucks belonging to a US freight company participated in the trial. Once fitted with the technology the vehicles maintained their normal freight hauling duties across the US. The trucks were allocated to one of three categories: ‘Test’, ‘Control’ or ‘Baseline’. The 50 vehicles in the test group were equipped with all three systems. The 30 Control vehicles were equipped with CWS only. The final 20 Baseline vehicles were equipped with a disabled CWS for the first 18 months of the FOT, and then with an enabled CWS for the remainder of the trial. Data was collected while the CWS was disabled but the driver received no alerts during this stage.

The Baseline and Control vehicles were fitted and in operation by early 2001 whereas the Test vehicles were fitted and operating in the second quarter of 2001. Data collection commenced in the middle of the year until the systems were removed from the vehicles in the second quarter of 2003.

The study found that a collision warning system with advanced cruise control and an advanced braking system can help reduce rear end crashes by 28 percent. Most of these accident reductions (21 percent) are due to the CWS, which is particularly effective at highway driving speeds. The study also found that the full CWS, ACC and AdvBS system could not be justified on a cost/benefit basis for all large trucks, however for tractor-trailer trucks (semi-trailers) there is a positive cost benefit. Interviews with test drivers also indicated that user acceptance was high (Batelle, 2007).

FCW Performance Evaluation (US, 2008)

In 2008, NHTSA evaluated forward collision warning (FCW) systems available as OEM equipment on passenger cars. All systems tested used an audio/visual warning interface and were available on three production vehicles (2009 Acura SL, 2009 Mercedes Benz S600 and 2008 Volvo S80). The tests were designed to evaluate the ability of the FCW systems to detect potential forward collision hazards under one of three scenarios and to provide an alert to the driver (Forkenbrock and O’Harra, 2009).

Three test scenarios were used to evaluate the systems. In the first scenario the subject vehicle drove towards a stationary lead vehicle. The second test involved the subject vehicle initially following the lead vehicle and maintaining the same speed as the lead vehicle. The lead vehicle then decelerated to a complete and sudden stop. In the third test the subject vehicle maintained constant velocity while the lead vehicle also maintained a constant velocity lower than that of the subject vehicle.

The tests were conducted off road, on a skid pad during daylight hours with good visibility.

Results of this testing were presented by Forkenbrock and O'Harra (2009). The authors found differences in system parameters, ranging from the method and timing of audio/visual alerts, to the estimated time to collision (TTC) for each vehicle.

PROTECTOR (Europe, 1999)

The PROTECTOR project was conducted in Europe from 1999-2003 to develop a system specifically for detecting and preventing accidents involving pedestrians. The project developed radar, laser and stereo-video based systems for warning drivers of the presence of a pedestrian (but not applying the brakes automatically). Systems were installed on one truck and two passenger vehicles.

Part of the project involved user testing of the system to determine the usability and acceptability of the warnings. This user testing was a relatively short trial and was not comprehensive enough to suggest any reduction in crash rate. In general the users rated the system positively for its usability but implied that the technology itself needed improvement (Gavrila 2009). Most participants tended to prefer an acoustic warning to a visual warning; except for truck drivers in the study that preferred combined acoustic and visual warnings. Results from questioning the participants did not indicate that the system would lead to risk compensation (Cicilloni 2003).

2.1.1 Discussion

Where results of trials have been reported, they have tended to focus on the effect of FCAT systems on rear-end crashes. It is likely that this is a consequence of the relatively high incidence of rear end collisions and effects are most likely to be apparent for this type of crash.

Collision avoidance systems are based on time to collision (TTC) algorithms, and these same algorithms may be applied irrespective of direction of travel of the potential collision hazard or the type of potential collision hazard (i.e. truck, pedestrian, motorcycle, car, stationary object). The main difference between rear end and other forward collision types is the time to collision, which may be much shorter for head on collisions.

Since collision avoidance systems are generally designed to provide both avoidance in all forward collisions (using the same sensors, braking systems and other technology) effectiveness in preventing rear-end collisions should indicate positive performance in other crash types.

The trials reviewed have tended to provide validation for collision avoidance technology, in either test track or on-road conditions using production vehicles. Several trials have sought to provide measures of system effectiveness and user acceptance of the systems evaluated.

In some cases it is not clear whether an apparent lack of trial results is because the trial was not carried through to conclusion or because the results have not been made publically available. Some trials have been conducted by private organisations or by system manufacturers so trial results have not been publically published. In some instances trials are ongoing and trial results have not yet been published. In others, problems in trial logistics have meant that no meaningful results were obtained.

Where trial results have not been sourced the available information on the trial has been provided for reference purposes.

2.2 Effectiveness estimates

2.2.1 Light vehicles

Sugimoto and Sauer (2005) estimated the effectiveness of an FCAT system introduced into the Japanese market in 2003. This was achieved by reconstructing around 50 rear end collisions with a simulation model that consisted of an accident scenario database, vehicle, driver, and environment model. The vehicle model included a radar model and the control logic for intervention of the FCAT system. It was found that the FCAT system would have avoided 38 per cent of the collisions. It was also estimated that the FCAT system would produce a 44 per cent reduction in the probability of fatality as a result of lowering the impact speed.

Najm, Stearns, Howarth, Koopmann, and Hitz (2006) conducted a field trial of a production intent rear end crash avoidance system for light vehicles. The system was a marriage of a forward collision warning system and an active cruise control system. The active cruise control would only brake a vehicle to a minimum speed of 32 km/h at a maximum of 0.3g. When the minimum speed was reached the driver was alerted to resume manual control. Such a system can be considered an early, relatively weak version of the forward collision avoidance technologies that are currently becoming available. A field test was conducted by 66 drivers over a combined distance of 163,000 km. The results of the field test led Najm *et al.* to conclude that the system may prevent about 10 per cent of rear end crashes.

Coelingh, Jakibsson, Lind and Lindman (2007) attempted to provide a real life safety perspective on a Volvo system that provided frontal collision warning with automatic braking. The authors acknowledged that total safety benefit was difficult to predict, however they did suggest that 50 per cent of rear end crashes could be prevented with the system.

TRL examined the costs and benefits of emergency braking systems in the United Kingdom in a report that also examined the technical requirements of such systems (Grover, Knight, Okoro, Simmons, Couper, Massie and Smith, 2008). In-depth crash data was used to determine that between 25 and 75 per cent fatal rear end accidents involving heavy vehicles would be reduced to serious injury crashes with such systems. Difficulties were noted in determining what crashes such systems would relate to, however it was assumed that the same percentage reduction would apply to other relevant crash types and severity levels. Break even prices (the price at which the benefit cost ratio would be one) were calculated by collision type for the current, near future and longer term. The near future values for light vehicles were between €136 and €966. Since the report was published in 2008 the near future values can be considered current. A benefit cost ratio was not provided, as a price was not able to be determined. Manufacturers claimed that the cost would be €1000 to €6000, thought the authors stated that there is some evidence to suggest the cost is in the order of €250 and that systems under development at the time aimed to cost less than €100. Grover *et al.* concluded that these systems are likely to be a very effective safety measure, producing a large casualty reduction and a positive benefit cost ratio in the near future.

Farmer (2008) noted that 38 per cent of crashes occurring the United States of America are relevant to FCAT. It was concluded that out of five emerging crash avoidance technologies evaluated, FCAT had the greatest potential. Jermakian (2011) updated the estimates of Farmer by accounting for known limitations in the current technologies. FCAT remained as the technology with the greatest potential, however the proportion of crashes that were considered relevant was reduced to 20 per cent.

Schiittenhelm (2009) investigated the real world safety effect of the Mercedes-Benz Distronic Plus system by using data on spare parts orders for specific combinations of spare parts that were known to be damaged at different impact severities. Distronic Plus is a combination of active cruise control, brake assist, forward collision warning and automatic braking that was an option on the S-class from 2005. The information from the spare parts orders was correlated with information from the German in-depth accident study to determine an overall safety benefit. It was found that 52 per cent of all rear end collisions could be avoided if the striking vehicle was fitted with the Distronic Plus system. It was also found that the system reduced rear end crashes by 24 per cent when the struck vehicle was fitted. The explanation provided by the author for this phenomenon was that the system caused earlier, less severe braking interventions and helped to avoid the last moment panic braking that can precede a vehicle being struck in the rear.

Georgi, Zimmermann, Lich, Blank, Kickler and Marchthaler (2009) from Bosch examined the potential effects of three components of Bosch's Advanced Emergency Braking System, Predictive Collision Warning, Emergency Brake Assist and Automatic Emergency Braking. The Predictive Collision Warning consists of acoustic and tactile warnings (in the form of a brake jerk) that activate when a critical situation is detected. The Emergency Brake Assist calculates the deceleration that is required to avoid a collision and activates this level of braking if the driver pushes the brake pedal in response to the warnings. Automatic Emergency Braking initially brakes at 0.3 g if a critical situation is detected. This level of braking is increased if the driver fails to react to this initial braking and the situation is still critical. The benefits of these systems were determined by applying a driver model based on an average driver and a model of the different systems to frontal crashes from the German in-depth crash investigation database. It was found that the crash reductions were 38 per cent, 55 per cent and 72 per cent for Predictive Collision Warning, Emergency Brake Assist and Automatic Emergency Braking respectively.

Kusano and Gabler (2010) examined the potential for occupant injury reduction in rear end crashes due to a forward collision avoidance system. A theoretical system was applied to real world crash data from the United States of America. The time to collision at which the theoretical system intervened was varied between 0.3 and 0.6 seconds. The severity of braking was also varied from 0.5 to 0.8 g. Two modes of deceleration were used; a constant magnitude pulse and a pulse that increased linearly at 25 m/s^3 until it reached the constant value. With a constant deceleration, a 30 to 57 per cent reduction in injuries was found. For the deceleration that ramped-up, the reduction in injuries was reduced to between 19 and 46 per cent. Kusano and Gabler refined their methodology to determine separate estimates for the striking and struck vehicles in rear end collisions (Kusano and Gabler, 2011). They found that the number of moderately to fatally injured drivers of the striking vehicle would be reduced by 36 per cent with a forward collision avoidance system. For the drivers of the struck vehicles a 28 per cent reduction was found.

Rosen, Kallhammer, Eriksson, Nentwich, Fredriksson and Smith (2010) sought to estimate the safety benefit that an autonomous braking system would have for pedestrian crashes. In particular they estimated this benefit as a function of the field of view of the sensor given braking intervention one second before the crash and a maximum deceleration of 0.6 g. Like Georgi *et al.* and Schiittenhelm, Rosen *et al.* utilised data from the German in-depth accident study. Rosen *et al.* found that fatal pedestrian crashes would be reduced by 44 per cent with the maximum field of view of 180°. At the much smaller field of view of 40° the reduction was only reduced to 40 per cent. For serious injury crashes the reduction was 33 per cent for the maximum field of view and 27 per cent for a field of view of 40°. Below a field of view of 40° crash reduction was reduced markedly.

The Highway Loss Data Institute (HLDI) conducted a preliminary analysis of insurance data relating to Volvo's City Safety technology, a type of FCAT system, in 2011. City Safety only functions at speeds below 31 km/h and is only capable of completely preventing a collision at speeds below 15 km/h. It also only recognises vehicles. The analysis found a 22 per cent reduction in collisions and a 27 per cent reduction in property damage liability relative to other similar vehicles without an FCAT. Claims for bodily injury were also half that of other comparable vehicles suggesting that the FCAT is also reducing injuries as well as property damage. That such results are achieved with a system that only works at such low speeds and is only designed to recognise vehicles is especially noteworthy.

Hummel, Kuhn, Bende and Lang (2011) investigated the potential safety benefits of various advanced driver assistance systems, including brake assistance systems, using insurance claims in Germany. A database referred to as the UDB was utilised, which contains data on crashes involving injury and at least €15,000 in total claim value. The authors' claim that the level of detail contained in this database is comparable to the German in-depth accident study data, though they acknowledge that no analysis is carried out at the scene. The safety benefit was determined by examining individual cases that were relevant to the technology and determining what the outcome would have been if the vehicle had been fitted with the technology in question. Hummel *et al.* estimated that an autonomous system that could detect other vehicles could reduce all crashes by 19.6 per cent. If the system could also detect pedestrians this increased to 24.5 per cent and if cyclists could also be detected this increased further to 43.4 per cent.

2.2.2 Heavy Vehicles

A field operational test of several technologies for heavy vehicles aimed at reducing rear end crashes was conducted by Battelle for the United States Department of Transport (Battelle, 2007). This study was referred to as the Volvo IVI FOT and is discussed in Section 2.1. These technologies included a forward collision warning system, active cruise control and electronically controlled braking system. It should be noted that the active cruise control evaluated does not operate the brakes as it does on light vehicles; braking is done purely through engine braking and downshifting. Deceleration rates range from 0.1 to 0.2 g. It was found that the combination of all of these systems could reduce rear end crashes by 28 per cent, with most of this reduction being attributable to the forward collision warning system (21 per cent). It was found that installing the forward collision warning system on semi-trailers would be cost effective and that the active cruise control may also be cost effective on these vehicles, however installing the systems on all large trucks over 4.5 tonnes was not cost effective.

Murray, Shackelford and Houser (2009) updated the cost benefit analysis conducted by Battelle (2007). Even though a lifecycle of only five years was assumed, the benefit cost ratio for a forward collision warning system was estimated to be between 1.6 and 7.2. The large range is produced by different levels of annual vehicle mileage and estimated efficacy of the system. The benefit cost ratio for forward collision avoidance combined with active cruise control was slightly lower, ranging from 1.4 to 6.3.

Rakha, Fitch, Arafeh, Blanco and Hanowski (2010) evaluated the benefits of a forward collision warning system for heavy vehicles. The benefit was determined by examining threatening events in the naturalistic driving study and applying the drivers predicted response if a forward collision warning system had been installed in the vehicle. It was concluded that such a system may reduce rear end crashes by 21 per cent.

Hummel *et al.* (2011), described in Section 2.2.1, also considered advanced driver assistance systems for heavy vehicles. A system that could only detect other vehicles (not pedestrians or cyclists) was considered. It was estimated that 12 per cent of heavy vehicle crashes could be avoided with an autonomous braking system. It should be noted that a maximum deceleration rate of just above 0.7g was assumed in the theoretical system. This is much higher than that achieved in the real system examined in Battelle (2007).

Grover *et al.* (2008), described in Section 2.2.1, also found break even prices for heavy vehicles. The near future break even price for heavy vehicles was €432 to €1,938. Since the report was published in 2008 the near future values can be considered current. A benefit cost ratio was not provided, as a price was not able to be determined.

2.2.3 Discussion

Light vehicles

Many of the studies that provided effectiveness estimates focused on rear end collisions. The estimates of the effectiveness of an FCAT system at avoiding a crash altogether varied from 10 to 72 per cent. Estimates of fatal rear end crash reductions were 36 and 44 per cent. The large range in crash avoidance potential may be due to different system parameters being used in each study and the coarse nature of using crash avoidance as a measure. For example, a weak system may rarely slow a car sufficiently to avoid a crash altogether though it is reducing the impact speed of the vehicle.

Only three studies considered crash types other than rear end crashes. Two considered all crash types; HLDI (2011) and Hummel *et al.* (2011). HLDI found a crash reduction of 22 per cent with a system that only operates at low speed. Hummel *et al.* found a reduction of 43 per cent. The other study considered pedestrians (Rosen *et al.*) and found a 40 per cent reduction in fatal crashes and a 27 per cent reduction in serious injury crashes. These figures are similar to the reductions found in the studies that only considered rear end crashes.

Two of the studies were based on real world results (Schiittenhelm, 2009; HLDI, 2011), unlike the rest of the studies that were based on modelling. While this does provide a very accurate picture of the effect of the system being considered within the demographic of the vehicle it is fitted to, it may not be representative of the entire fleet. Studies that rely on modelling take into account the crash patterns of the entire fleet but must often make assumptions about how the system will operate in the real world. It is difficult to determine which type of study produces the most accurate estimate of the overall effect of FCAT.

Only the study by Grover *et al.* (2008) attempted to conduct a benefit-cost analysis. FCAT system prices were uncertain so break even prices were calculated rather than a benefit-cost ratio (BCR). The break even prices ranged from €136 to €966. The large range in break even prices was a result of a large range of assumed effectiveness. The authors stated that FCAT systems would be cost effective in the near future.

Heavy vehicles

Both studies that estimated the potential of FCAT systems to reduce heavy vehicle rear end crashes estimated a reduction of 21 per cent. The study that considered all heavy vehicle crashes estimated a reduction of 12 per cent. These estimates are at the lower end of the range that was found for light vehicles.

Three studies considered the cost effectiveness of FCAT systems for heavy vehicles. Battelle (2007) found an FCAT system would be cost effective on semi-trailers but not on all heavy vehicles. Murray, Shackelford and Houser updated this finding in 2009 and found that the BCR ranged from 1.6 to 7.2. Grover *et al.* found that break even prices for heavy vehicles ranged from €432 to €1,938. These studies suggest that FCAT system are cost effective on heavy vehicles.

3 Potential administrative, regulatory and infrastructure issues

This section examines various issues that could affect the successful implementation of FCAT across the vehicle fleet.

3.1 Administrative issues

3.1.1 Product liability

Product liability is generally thought to be an issue in the USA but experience there may be applicable to Australia. Bhatia (2003) notes:

> “This is always a concern when new products are involved, the fear of lawsuits has helped slow the introduction of adaptive cruise control in the USA. A mock trial held at the 44th Annual Meeting of the Human Factors and Ergonomics Society in San Diego, CA (2000) demonstrated how the plaintiff, the driver of a vehicle equipped with ACC can seek damages from the defendant, the manufacturer of the vehicle, for inappropriate design of the ACC that the driver alleges contributed to a motor vehicle collision in which she was involved. The underlying issue concerned the handover of control from the vehicle to the driver under conditions of partially automated driving.”

It is not known if there have been subsequent lawsuits in the USA on this issue.

The focus of product liability law in Australia is on a defective product that causes personal injury. The incidence of product liability claims made against vehicle manufacturers in Australia is much lower than in the United States. Furthermore, courts in Australia have shown willingness to accept a defence that products complied with the state of scientific knowledge at the time the goods were supplied, and have been conservative in their judgements as they relate to liability (Little, 2005). Hence, with the definition of appropriate standards or recommended practices that the product can be designed to meet, the risk of product liability issues should be minimal in Australia given the present state of the common law. It is worth noting that no adverse effects of FCAT systems deployed to date have been reported, manufacturers have shown a willingness to release product, and it must be assumed that issues around product liability have been considered before product release.

An issue that does not appear to have been raised in connection with product liability is any increased risk of an FCAT vehicle being struck from the rear, after it has successfully prevented a forward collision. It could be argued that in most cases a collision was inevitable and therefore the following vehicle would still have struck the FCAT vehicle. Of relevance here are the results of Schiittenhelm (2009): vehicles fitted with FCAT systems were also less likely to be struck in the rear and the explanation offered was that the system caused earlier, less severe braking interventions and helped to avoid the last moment panic braking that can precede a vehicle being struck in the rear.

However, it would be advisable to evaluate the effect of FCAT systems on the incidence of crashes in which the FCAT vehicle is not struck from the front, to ensure that vehicles are not at increased risk of such crashes, providing a definition of the state of relevant scientific knowledge as it relates to the common law.

3.1.2 Vehicle manufacturer warranties

OEM-fitted systems are expected to be fully covered by the vehicle manufacturer warranty.

Retro-fitting FCAT systems to vehicles is a possibility, particularly camera systems that attach to the inside of windscreens. However their introduction could be hampered by concerns about the effect on vehicle manufacturer warranties. There seems to be little incentive for manufacturers to work with after-market suppliers to overcome these concerns.

3.1.3 Vehicle insurance cover

Premiums might rise where the collision sensor system is expensive and in a location that is easily damaged in a minor collision, such as some front-mounted radar systems.

On the other hand, the early insurance industry experience with FCAT appears to be favourable. The HLDI reported that property damage claims in the USA were 25 per cent less frequent with the Volvo XC60 fitted with City Safety, compared with other SUVs without FCAT (HLDI, 2011).

3.1.4 Public acceptance

There may be an issue with drivers and other road users accepting the fact that the vehicle effectively takes control from the driver, albeit for just a few seconds. Public education will need to stress that these systems are reliable; that they are only designed to intervene when the opportunity for driver action has passed and that they are not prone to inadvertent operation. To some extent, these assurances will depend on the thoroughness of the standards that are developed for FCAT.

In trials of FCAT, drivers are reported to have quickly become accustomed to the system and find it a "stress reliever" (Bhatia 2003).

Another public concern is that drivers could become too reliant on the FCAT system and engage in riskier driving such as following too closely or text messaging.

3.1.5 Reliability

Bhatia notes that the biggest challenge to FCAT is avoiding false alarms. False audible and visual (head-up) warnings might be annoying but a false braking episode could be dangerous in some circumstances. That is why many of the performance tests being developed by independent organisations such as RCAR include tests for false alarms.

3.2 Regulatory issues

Vehicle safety regulations might need to be introduced or amended to cater for FCAT. Regulation might require the inclusion of worthwhile in-vehicle technologies on certain vehicles and/or to ensure that there are no adverse effects from in-vehicle technologies.

There may also be a need for published standards or guidelines that set out design or performance requirements for FCAT - amongst other things this may help protect innovative manufacturers from litigation. The Society of Automotive Engineers (SAE) Recommended Procedures are an example of such standards.

Regulations might be needed to ensure there are no adverse effects from an FCAT and to promote compatibility. For example, Annex 18 of United Nations ECE Regulation 13 (Commercial Vehicle

Braking) defines functional requirements, fault strategies and methods of verification of "complex electronic vehicle control systems" where fitted to commercial vehicles. The Annex was apparently developed to cater for commercial vehicle ABS braking systems in the 1980s but its provisions are considered flexible enough to also cover new technologies such as FCAT.

The normal practice for Australian vehicle regulation under the Australian Design Rules is to do so in line with international standards as much as possible.

International standards could take the form of a United Nations Economic Commission for Europe (UNECE) Regulation or a Global Technical Regulation (GTR) through the World Forum for Harmonisation of Vehicle Regulations (WP29) of the UNECE, under the 1958 or 1998 Agreements.

At this stage, the development of a UNECE Regulation or GTR for FCAT systems for light vehicles does not appear to be a stated goal, and so may be several years away. For heavy vehicles, there is currently a draft UNECE Regulation being developed, using the term Advanced Emergency Braking Systems (AEBS). Consideration of this as a national regulation for Australia, once finalised, is an action under the National Road Safety Strategy 2011-20. More detail on this draft UNECE regulation can be found in Appendix A. It is understood that once a UNECE regulation is developed for heavy vehicles, WP29 would then consider the technology for light vehicles as well (Hoy S, personal communication, April 19, 2012).

As Australia is a signatory to the UNECE 1958 Agreement on Uniform Technical Prescriptions for Wheeled Vehicles and 1998 Agreement on Global Technical Regulations for Wheeled Vehicles, that forum appears to be, at least in practice, the most appropriate one in which to pursue a standard with which Australia can harmonise.

Furthermore, it is probable that in-field performance will need to be demonstrated beyond reasonable doubt before a case can be mounted for mandating fitment of FCAT systems using the Motor Vehicle Standards Act 1989. The precedent of electronic stability control may be instructive: both an international standard (via processes under the UNECE 1998 Agreement on Global Technical Regulations) and multiple in-field evaluations preceded the move to regulate in Australia.

Prior to, or as an alternative to mandating FCAT systems, an Australian Design Rule might define requirements for optional systems (as is the case for anti-skid braking systems for motorcycles). An advantage of an optional rule would be to allow flexibility in the introduction of systems into the Australian market, while guaranteeing a minimum level of performance, and an absence of unintended system behaviour in product supplied in the Australian market.

Whether or not the ADR is mandatory, previous comments regarding the prerequisite of an international standard are likely to be relevant. Therefore the timing of any introduction of an ADR is likely to be dependent on the timing of international regulations, and the readiness of manufacturers to comply.

In the interim, the most promising FCAT standard that could be used in Australia in the near term is the protocol being developed by a Euro NCAP working group for consumer rating purposes. Another recommendation of this report is that ANCAP give substantial credit to manufacturers who install effective FCAT systems on their vehicles, as part of vehicle assessments.

3.2.1 Radio frequency management

The Australian Communications and Media Authority (ACMA) issued this media release (last updated 2009):

> "Intelligent cruise control systems, which can actuate a motor vehicle's brakes and/or accelerator to control its distance separation behind another vehicle, are appearing increasingly on transport and passenger motor vehicles around the world. Most of these systems sense distance separation using short range automotive radar devices.
>
> In September 2000 the former ACA began working with the Federal Chamber of Automotive Industries (representing a number of vehicle manufacturers) to determine how the use of automotive radar devices might be supported in Australia (use of radar devices requires a radio communications licence).
>
> The former ACA completed a technical study in April 2001 that examined international arrangements for these devices and the potential effects of their use on domestic spectrum users. The paper recommended that a Class Licence, the Radio communications (Low Interference Potential Devices) Class Licence 2000 would be the appropriate licensing option to authorise use of these devices Australia wide. After considering public and industry comment, this Class Licence was subsequently amended in September 2001 (see also ACA media release 57/2001). Schedule 1, Item 47 of this Class Licence provides support for the automotive radar devices used in intelligent cruise control systems."

FCAT can use the same radar technology as intelligent cruise control and so it appears to be covered by these arrangements.

However, it is not clear whether all current types of vehicle radar are legal to use in Australia as they might be operating at frequencies that are outside the Class Licence.

ITS Australia, in its recently published draft "National Intelligent Transport Systems Industry Strategy - 2012-2017" makes brief reference to the radio spectrum issue and notes that ACMA is a regulatory stakeholder (ITS Australia, 2012).

In 2011 the European Commission issued a press release that stated:

> "Authorisation to use the 24 GHz radio frequency band for short-range anti-collision radar in cars has been extended until 2018 by a European Commission decision. This temporary extension will ensure short range car radar systems remain available on the market until manufacturers develop technology using the 79 GHz band, which was the operating frequency designated for such systems back in 2004."

Radio frequency allocation is also an issue with vehicle-to-vehicle communications, as described in the next section.

Evidently the issue of radio spectrum allocation remains an issue around the world and could hamper innovative FCAT.

3.3 Infrastructure issues

3.3.1 Road design that is compatible with FCAT systems

Roadside furniture can be a source of false alarms from FCAT systems. A study by Carpenter *et al*. (2011) found that over 22,000 miles of driving an FCAT system using Radar only produced about 100 false intervention events, however when a combination of radar and camera was used no false intervention events occurred. A US DoT-funded study by Carnegie Mellon University (Mertz *et al.*, 2005) noted the substantial challenges exist in producing reliable collision warnings in the urban environment, particularly with transit bus operations.

While it is possible that the design of the road and roadside could aid in the effective operation of FCAT systems it is unlikely that road authorities would retrofit all roads to ensure FCAT compatibility: it is also unlikely to be cost effective to do so. Even if new roads were designed and built to specifications that ensured FCAT compatibility, the FCAT systems would still need to operate effectively when not on such roads. For these reasons it is far more likely that the FCAT system manufacturers will improve object recognition to reduce false positives caused by the road or roadside. The US Federal Motor Carrier Safety Administration has issued reports on this topic. Houser *et al.* (2005) pointed out that FCAT systems "... should be capable of differentiating stationary roadside objects such as guardrails, signs, and bridges from moving vehicles in both the travel lane and opposing lanes". Such capability could be tested as part of regulations discussed in Section 3.2.

4 Technologies and costs

4.1 FCAT related technology

This section outlines the various technology underpinning forward collision avoidance systems.

Several manufacturers now have vehicles on the market with forward collision avoidance systems. Australian models of the Mercedes Benz S Class and the E 63 AMG are equipped with the Pre-Safe BRAKE system, which includes object detection and autonomous emergency braking. The Volvo S80, XC60 and XC90 come with the City Safety system, which includes object detection and autonomous emergency braking. Lexus and Audi also have models equipped with FCAT technology currently in the Australian fleet and Subaru is soon to release the EyeSight forward collision avoidance system in an update to the Subaru Outback. The MobileEye C2-270 is an aftermarket forward collision warning system and has been installed in various light and heavy vehicles across Australia. These are a sample of the systems currently available and it is expected that provision of forward collision avoidance systems on new vehicles will increase in future.

The technology and characteristics of these systems varies between systems, particularly with regards to the method of detection of hazards, which governs the speeds the system will function at and the types of object the system will detect. For example, Volvo City Safety is designed to operate at speeds between, 4 km/h and 30 km/h whereas the Mercedes Benz Pre-Safe system operates at speeds between 30 km/h and 200 km/h. Furthermore some systems (such as the MobileEye C2-270) provide only an audio/visual collision warning, whereas others (such as the Mercedes Benz Pre-Safe, Subaru EyeSight and Volvo City Safety) automatically brake the vehicle if there is no action by the driver. Parameters such as volume of warnings, timing of warnings/action after detection and level of braking (if any) also differ between systems.

TRL (Grover *et al.*, 2008) divides FCAT systems into three broad categories:

- Collision avoidance (FCA) – Where a system detects an imminent collision and automatically takes action to attempt to completely avoid the collision (i.e. generally through emergency braking).
- Collision mitigation braking systems (CMBS) – Where a system detects an imminent collision and automatically takes action to reduce the severity of the collision (again generally through emergency braking) but does not seek to avoid a collision altogether (i.e. a collision will still take place, but at reduced velocity).
- Forward collision warning (FCW) – Where a system detects a potential collision and provides an advisory warning to the driver so that the driver can take action to avoid the collision.

Systems currently on the market often fall into more than one of these categories.

4.2 FCAT system sub-components

FCAT systems are made up of a number of sub-components that are connected and interrelated, but generally distinct from each other. For example, one sub-component detects objects in front of the vehicle, another sub-component processes the detection data and decides if a collision is imminent, another component provides an alert to the driver (where available) or activates autonomous braking (again, where available).

These sub components are often shared by other vehicle systems, for example the braking system on an FCAT system may be shared by the electronic stability control system. The data processing unit may also process data from other vehicle sensors for other in-vehicle systems and the detection system may be used to trigger a pop-up bonnet for pedestrian impacts.

As such an FCAT system is not a stand alone system and often builds upon other technology already present in the vehicle.

4.2.1 Detection system technology

Several options are available as a means of detecting potential collision objects and these are described below. The detection systems may be used in combination (sensor "fusion") to improve range, reliability and/or increase the number of object types that can be detected.

Grover *et al.* (2008) describes sensor fusion as:

> “Combining multiple sensing technologies to supplement, enhance and improve the reliability of a sensing system. Using one sensor technology to compensate for the drawbacks of another is a common practice in sensor fusion applications. A common fusion application involves the combination of radar or laser scanner and image sensing system. Sensor fusion offers the potential to gather additional information describing the vehicle operational environment and any obstacles but complex algorithms are necessary to interpret the data gathered.”

Radar systems

Radar is the most widely adopted detection technology for FCAT systems (Grover *et al.*, 2008) and radar systems are often comprised of both short range (approximately 0-50 m) 24 GHz radar and long range (approximately 50-200 m) 77 GHz radar systems, although in some cases only one type of radar system is used. Short range radar has wider horizontal field of view (FOV) of up to 40 degrees whereas long range radar has a much narrow horizontal FOV (typically 10-15 degrees). The FOV is critical when approaching collision hazards on a curved road section, however a wider long range FOV is more likely to result in false alarms (as roadside objects are more likely to be detected).

Radar is popular due to high reliability, durability and versatility (having both long and short range applications) for a comparatively moderate cost. However performance is reduced in wet conditions, particularly for long range radar and may not detect objects with poor radar reflectivity (such as objects of a size similar to, or less than the radar wavelength or objects that are low in metal content) (Grover *et al.*, 2008)

Laser systems

Laser or lidar (light detection and ranging) sensors calculate the distance to an object by measuring the time it takes to receive a reflected signal. Varying the direction of the emitted beam facilitates scanning over a wide area at high frequency to build up a map of points describing the environment and any potential obstacles (Grover *et al.*, 2008). Repeated scanning of an object allows the position and relative velocity to be determined, with higher frequency scanning resulting in a more accurate estimation.

Although laser systems are superior to radar in some ways, they are susceptible to reflection, refraction, absorption and scattering and require complex shape and motion recognition algorithms to be able to differentiate between different types of object (Grover *et al.*, 2008).

As laser systems require line of sight they are unable to detect objects obscured behind other objects or during fog or heavy rain.

Vision based (camera) systems

Camera detection systems may use one (mono) or two (stereo) cameras. Because distance measurement is difficult using a vision based system, complex analysis is required to identify objects and determine their position speed and direction of travel.

The Subaru EyeSight system uses a stereo camera and is able to differentiate between a wide range of objects (Subaru, 2011). Volvo's Citysafe system uses a mono camera in conjunction with short and long range radar.

Vision based systems are less expensive than radar or lidar systems but are more expensive than IR or ultrasonic.

Processing systems have developed to a stage where the processing requirements are no longer a significant disadvantage. Performance of optical systems is reduced by any environmental condition that would affect normal human sight such as heavy rain, fog or sun glare and are susceptible to debris covering the camera lens. (NHTSA, 2011).

As with laser systems, camera systems require line of sight and they are unable to detect objects obscured behind other objects or during fog or heavy rain. They may also have difficulty with low ambient light levels, such as at night.

Infrared sensors

Infrared (IR) sensors detect infrared light emitted from or reflected off objects. There are two types of IR detection system; active, where an IR emitter is used to generate the IR signal and passive, where the sensor detects IR emissions (generally in the form of heat given off by the object). They are compact, provide good object detection for some objects and are suitable for pedestrian detection, (Grover *et al.*, 2008)

Because they do not rely on light in the visible spectrum, IR sensors are often used for forward detection systems designed to operate at night.

Infrared sensors can be poor at differentiating between multiple warm objects in close proximity that may result in the system incorrectly identifying objects and can be influenced by the presence of thermal insulation or environmental conditions.

Cool objects such as cars may not be reliably detected and infrared is usually used in conjunction with other sensor systems. Similarly, hot ambient conditions can reduce the effectiveness of infrared sensors (Grover *et al.*, 2008).

Ultrasonic sensors

Ultrasonic sensors use reflections generated by high frequency sound waves and are accurate enough to determine distance, angular position and velocity of approaching obstacles. Ultrasonic sensors have short response times and are a relatively low cost option, however their performance is only suitable for short and medium range application. They are highly sensitive to changes in operating voltage, which leads to inaccuracy, and they are susceptible to performance degradation due to reflected signals (Grover *et al.*, 2008).

4.2.2 Vehicle inputs

The system may use a number of inputs from the vehicle in the calculation of whether there is a potential crash scenario and to determine the course of action the system should take.

Wheel oscillation sensors or GPS may be used to calculate vehicle speed, GPS or steering angle may be used to determine direction of travel and the position of the brake pedal may be used to determine whether the system should engage (if the driver is already reacting sufficiently the system may decide to leave control of braking to the driver).

4.2.3 Control system

The control unit analyses detection data inputs and vehicle inputs and decides if action should be taken and what action is required (e.g. the type of audible warning or the level of braking) by calculating the vehicle's relative position and speed to an oncoming object. The control system also monitors the brake pedal to apply a higher braking force if the driver has not actuated the brake sufficiently, or to cancel autonomous braking or warning alerts if the driver has applied the brakes sufficiently. The control system is also responsible for identifying false alarm conditions (ADAC, 2011).

Since processing uses a small, but potentially significant amount of time, the amount of time it takes the control unit to process the detection data inputs and take action (e.g. provide an alert or initiate braking) should be as small as possible, without increasing the risk of false alarms. The greater the delay between detecting a collision hazard and taking action becomes, the higher the likelihood that there will be insufficient time to avoid the collision.

Wilson *et al.* (1997) recommends a system delay time of 300ms or less and UMITRI (2003) recommends a maximum processing lag time of 100ms in the control unit.

4.2.4 Human Machine Interface (HMI)

The HMI encompasses interactions between the driver and the FCAT system including the type of alert (if any) the driver will receive, any other type of feedback, any braking intervention, and any variable settings of the system. Variable settings may include the alert volume, alert type, set following distance or the maximum vehicle speed limit. Variable settings will differ between various systems (ADAC, 2011).

System settings

Some collision avoidance systems permit adjustment of various settings to allow the driver to customise the system to suit their own preferences.

Examples of settings that can be adjusted in some systems include: volume of alerts, visual alert and display brightness, and minimum headway gaps (distance to the vehicle in front) based on distance or minimum time to collision.

Some systems, such as the Volvo City Safety, allow the user to deactivate the system entirely (Volvo Cars Australia, 2011a).

However there is some danger in allowing driver control over settings that affect how the system operates. McCallum *et al.* (2006) referencing Campbell *et al.* (1996) point out that drivers may inappropriately adjust the controls to settings that reduce or eliminate the effectiveness of the system such that alerts are presented too late to effectively warn the driver of an imminent collision. Similarly if a system can be deactivated it may not be reactivated by the driver (or subsequent drivers if the system remains deactivated when the engine is shut down).

As a measure to discourage drivers from adjusting settings while driving, settings should not be adjustable while the vehicle is moving unless absolutely essential. Campbell *et al.* (2007) suggest that complex interactions, such as initial control settings, should be reserved for times when the vehicle is stopped.

Alert provision

The driver must easily and readily understand any alerts. The system should avoid false alarms, should not distract the driver unnecessarily and should ensure that any visual alerts are within the driver's normal field of view.

Alerts may be audible, visual, haptic, or a combination of these.

Options for visual alerts include:

- Singular (e.g. a light), either as fixed or variable (flashing, changes in colour or intensity) and spatially localised (located in the direction of the location of an alert or warning)
- Visual icon (e.g. symbols and pictograms)
- Sequences of visual displays designed to mimic movement (and to convey relative speed).

The size, colour or intensity of these may differ between systems, as may the location of the alert (e.g. heads up display, instrument cluster, multimedia screen).

Auditory alerts and warning may be:

- Singular (tones, buzzers), either as fixed or variable, including rate and method of presentation, changes in tone (frequency) or loudness (intensity) and spatially localised (located in the direction of the location of an alert or warning)
- Auditory icons, or sounds that imitate real world events (e.g., a shutter sound to indicate the location of camera enforcement)
- Verbal, or speech

The alert may utilise the vehicle's speaker systems (as for the radio, CD player and/or auxiliary media input), or may utilise a separate speaker source. The audible alerts may override any media playing through the speakers, however no current production systems have this feature (although it is a feature on some in-vehicle systems, such as intelligent speed assist and Bluetooth linked mobile phone systems currently available in the market).

Haptic (tactile) alerts may be transmitted through the steering wheel, seat or pedals (although there is potential for other vehicle components to be utilised). To date the brake pedal has been favoured for haptic feedback in production vehicles (ADAC, 2011).

Campbell *et al.* (2007) provide some guidelines on the design of a FCAT HMI system, particularly with regard to the design of audible/visual/haptic alerts, integration of different alert types and avoidance of false alarms.

4.2.5 Braking system

Of systems currently on the market there are differences in the level of braking. Some systems on light vehicles, such as Subaru EyeSight and Mercedes Benz Pre-Safe have phased braking intensity, where only light braking is applied at first (at a stage where it is likely that the driver can still take action to avoid a collision), then heavy braking when a collision becomes imminent. The level of braking at the various stages of intensity varies between systems. Other systems such as Lexus' Pre Collision Safety System in the LS 600hl have one level of braking only.

Some systems for light vehicles pre-charge the brakes by filling the brake circuit with brake fluid so that as soon as the brakes are triggered the full braking effect is available almost instantaneously. (Grover *et al.*, 2008).

It has been suggested that, for light vehicles, automatic emergency braking should only be programmed for high levels of braking that will cause discomfort to the vehicle occupants (Wilson 1997). This would discourage drivers from relying on the technology for normal driving (i.e. using it like adaptive cruise control).

Braking for heavy vehicles often uses a pneumatic circuit that takes longer to achieve full braking power than the hydraulic systems commonly used on light vehicles. Furthermore the large mass of a heavy vehicle (particularly if fully laden) means that the stopping distance required is often longer than for a light vehicle travelling at the same speed. This means that collisions avoidable through heavy braking for light vehicles may not be avoidable for heavy vehicles.

Braking is also more complex for a heavy vehicle in that the dynamics of the load and differences in brake effectiveness between the tractor and trailer mean that braking must be controlled to avoid roll-over, fishtailing or overrun.

4.3 FCAT system costs

4.3.1 Cost variation

System costs will vary depending on the type of detection sensor used (i.e. radar, lidar, optical, etc) and whether the system provides audio-visual alerts only or implements collision avoidance braking.

System costs can also be difficult to determine since some crucial components may be shared by other vehicle systems (e.g. braking components and processing units) so these components are a partial cost for any system that uses them.

4.3.2 System costs in Australia

In Australia FCAT system components are commonly included as standard on vehicles, even if full functionality is not enabled as standard. For example, purchasers of the T6 and T6 R variants of the Volvo S80 must pay $4175 on top of other vehicle costs to have adaptive cruise control with distance alert and collision warning with auto brake enabled, even though the detection, braking and processing components are already fitted to the vehicle. The system is standard with the V8 variant (Volvo Cars Australia, 2011b). Similarly customers purchasing the BMW 7 series must pay extra for the adaptive cruise control with stop and go function, unless the top 760Li variant is chosen (BMW, 2011)

Requiring the customer to purchase an optional enhancement package to receive full FCAT functionality is common on Australian vehicles and packages often include systems not related to FCAT. For example, the optional enhancement pack for the Lexus GS 250 is $6000 and includes Lexus' Pre Collision Safety System, however the cost of the enhancement pack also covers a moonroof, automatic high beam headlights and head-up display. (Lexus, 2011) and the cost of the Subaru Eyesight system packaged with satellite navigation is $2500 to the consumer, according to Subaru (The Motor Report, 2011)).

The Mercedes Benz CLS comes with the Pre-Safe system as standard but for the optional Pre-Safe automatic brake to be enabled the customer must purchase an optional driver assistance package (Mercedes Benz, 2011)

An aftermarket FCAT system available in Australia was identified, the Mobileye C2-270. This system is a camera-based forward collision warning system and costs approximately $1000 to fit on a per vehicle basis (personal communication, 2012).

Approaches were made to vehicle manufacturers (or their representatives) in Australia however no other information was forthcoming about FCAT system costs.

4.3.3 Overseas system costs

Bhatia *et al.* (2003) reports the cost of the radar based Eaton-Vorad system at $2500 while heavy vehicle headway warning systems available on Isuzu, Mitsubishi, Hino and Nissan vehicles in Japan cost approximately $5000. Bhatia *et al.* also provided the information in Table 4.1 on forward collision avoidance system costs for systems available in Japan. The prices shown are from 1998.

Table 4.1
Japanese forward collision avoidance system costs (1998)

Company	Model	Product Name	Launch Date	Cost ($US)
Mitsubishi	Diamante	Pre-view Distance Control	July 1995	$3,660
Mitsubishi	Debonair	Distance Warning	Oct 1992	$5,990
Mitsubishi	truck & bus	Distance Warning	July 1993	$5,000
Hino	truck & bus	Safety Eye	May 1992	$4,500
Nissan	truck & bus	Traffic Eye	Dec 1989	$4,500
Isuzu	truck & bus		Dec 1990	$2,300
Toyota	Estima, Hi-Ace	Clearance Sonar	Aug 1989	$760
Nissan	Largo	Corner and back sonar	May 1993	$900
Honda	Odyssey	Corner and back sonar	Oct 1994	$760

Taken from Bhatia *et al.* 2003

Murray *et al.* (2009) lists a typical OEM list price for a forward collision warning system of $2000 with an additional price of $300 for integrated adaptive cruise control. This is similar in magnitude to system costs provided by TodaysTrucking.com (Todays Trucking, 2007) of $1,000 to $3,000 per vehicle for an installed collision avoidance system plus an additional $350-$400 for an integrated ACC system. The differences in cost are due to variation in system features and the amount of units purchased.

In a review of FCAT systems available on European vehicles in 2011 ADAC listed the system costs shown in Table 4.2 for FCAT systems available on assessed production vehicles (ADAC, 2011).

Table 4.2
Collision avoidance systems costs on European production vehicles (ADAC, 2011)

Vehicle	Also available on	System name	System features	Cost
Volvo V60 D5 AWD Geartronic	S60, XC60, S70, V70, V80	ACC incl. Full Auto Brake	FCW, ACC, Brake assist, autonomous braking	€1,700* ($2,125)
Mercedes CLS 350 BlueEfficiency	E-Class, S-Class	Driving assistance package plus:	FCW, ACC, Brake assist, autonomous partial braking	€2,678 ($3,347)
Audi A7 3.0 TFSI quattro	A6, A8	ACC incl. pre-sense:	FCW, ACC, brake assist, autonomous braking	€1,460 ($1,825)
VW Passat Variant 2.0 TFSI DSG Highline	Passat, Passat CC	ACC incl. Front Assist:	FCW, ACC, brake assist, autonomous partial braking	€1,195 ($1,493)
BMW 530d Automatic	5-series Touring, 5-series GT, 7- series	ACC incl. Adaptive Brake Assistant:	FCW, ACC, brake priming	€1,550 ($1,937)

*Citysafe system which provides components used in detection fitted as standard

It is likely, as has been the case with other in-vehicle technologies that the cost of FCAT systems will reduce over time as the technology matures and uptake increases.

5 Estimation of benefits

Theoretically, forward collision avoidance technologies are likely to be highly effective as they are designed to reduce impact speed, and hence crash energy. Injury risk is non-linearly related to crash speed, and therefore risk may be reduced disproportionately to the impact speed reduction produced by an FCAT system. In some cases, crashes will be avoided altogether.

The mechanism of the effect is largely predictable: braking is optimised and effective reaction time (which is normally a human factor) is reduced. Both these effects reduce stopping distances and the speed of the vehicle at any given point along its stopping path.

Because the mechanism is predictable, the effects of FCAT systems are amenable to simulation. If the paths of vehicles (or other road users) in a collision are known, the collision can be described numerically in terms of the speed, direction, and the timing and strength of braking. Once the crash is described, FCAT effects can by superimposed on the collision history, and the effect of the FCAT system on the collision speed can be simulated.

The objective of this part of the report is to use this in-depth crash data to estimate the effects that FCAT systems might have on the incidence and severity of crashes and to estimate the benefit-cost ratio on such systems based on the predicted reduction in crash involvement of FCAT equipped vehicles, and the costs of exemplar technologies.

5.1 Methodology

5.1.1 Overview

The process by which estimates of the benefits of FCAT systems were arrived at is described graphically in Figure 5.1. The process was as follows:

- Mass crash data was used to select the most common injury and fatal crashes that are relevant to FCAT systems.
- Cases from CASR's in-depth crash investigation database were selected to represent the relevant crash types found in the mass data.
- The selected in-depth cases were simulated to determine trajectories and closing speeds.
- The specification (general performance) of FCAT systems, based on information from manufacturers and technology providers, was parameterised.
- A collision detection and intervention model based on these parameters was applied to the simulations of in-depth cases to determine a new closing speed to simulate the effects of the FCAT system.
- Average risk reduction in each crash type was based on a relationship between closing speed and injury crash or fatal crash risk.
- Overall benefits were estimated by calculating the average benefit over all crash types, appropriately weighted by the frequency of each crash type in the mass crash data.

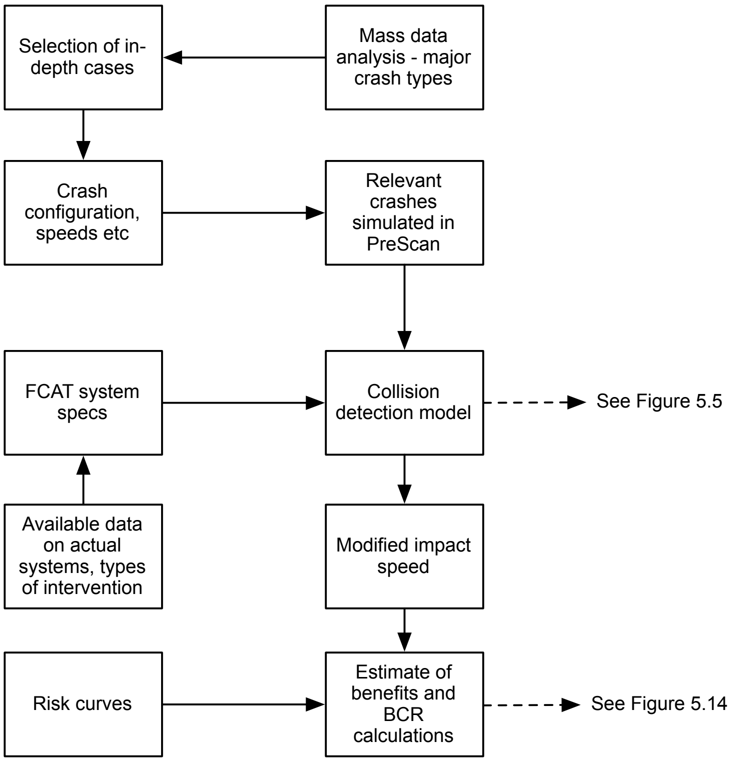

Figure 5.1
Methodological flow of calculating the safety benefit of FCAT

5.1.2 Identification of relevant frontal collision crash configurations

To determine the prevalence of crash types that may be applicable to FCAT, mass crash data was analysed. The mass crash database considered for analysis is based on the 228,750 crashes that occurred in NSW between 1999 and 2009 causing injury or death. The crash records were obtained from Transport for New South Wales through the NSW CrashLink system.

The key variable in the mass data used in the analysis was the Definition for Coding Accidents, otherwise known as the DCA code. The DCA code describes the movements of the vehicles involved in the first impact that occurred during the crash. The DCA is coded according to a “key vehicle” which is designated by the darker arrow in the DCA legend (see Figure 5.2).

Crashes where the FCAT system has the potential to influence the crash outcome are those where the front area of a vehicle ‘leads’ in a particular crash configuration. For the purposes of this report we refer to this vehicle as the “FCAT Vehicle”.

For example, in a rear-end collision, it is the FCAT vehicle that collides with the rear of another vehicle. The DCA legend defines this vehicle as the key vehicle in almost all rear end collision codes (DCA 301-303). In the case of a rear-end collision with a vehicle undertaking a U-turn (DCA 304) the DCA legend nominates the struck vehicle as the key vehicle.

Though the DCA “key vehicle” is generally the FCAT vehicle for the purposes of this project, it was important to make the distinction in each DCA code. Figure 5.2 shows the DCA legend. Two reverse arrows (<<) in the top right corner of a DCA box indicate that the key vehicle is not the FCAT vehicle and that the FCAT vehicle is the second unit described in the database. This distinction was made to ensure, as far as possible, that the analysis of crashes focused on the vehicle in the crash that, if an FCAT system was installed, would be the most likely to affect collision speed in the collision.

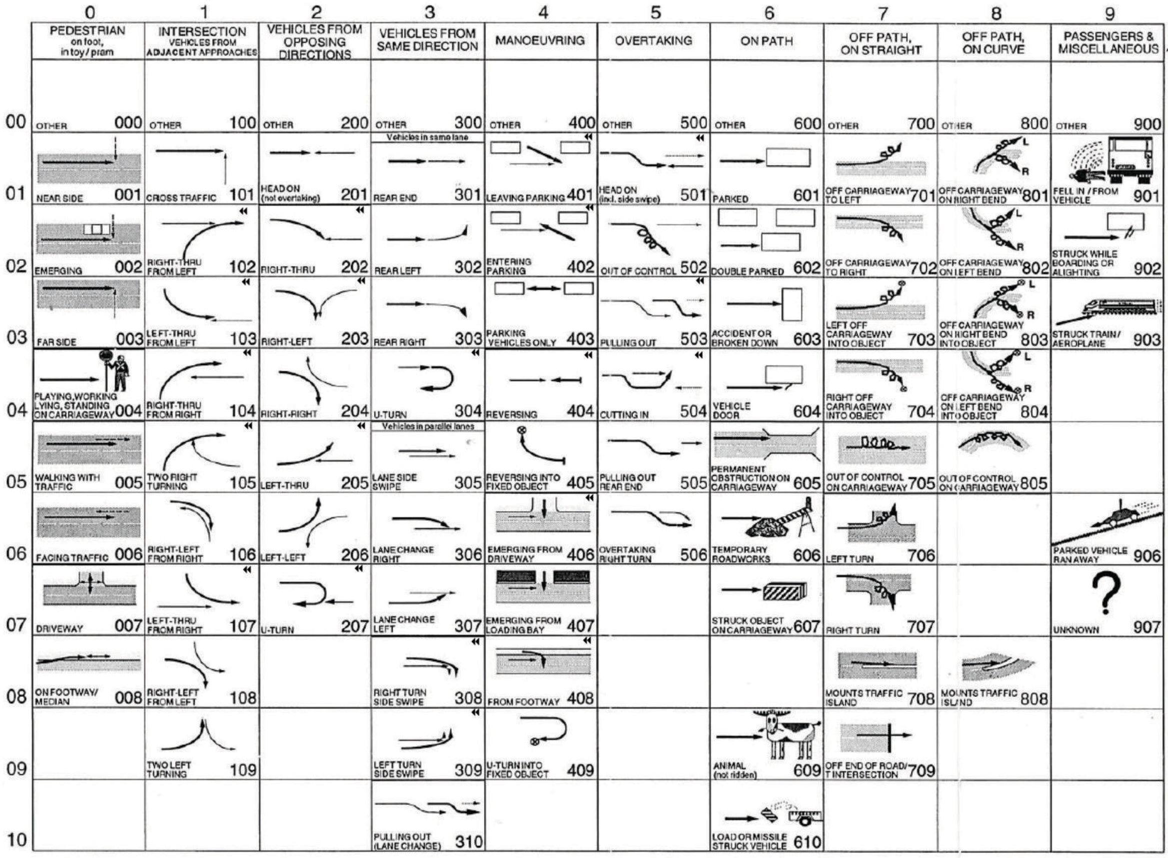

Figure 5.2
DCA Code Legend, note (<<) symbols indicating where DCA, 'key vehicle' was not FCAT Vehicle

DCA codes were then grouped into similar types with respect to likely FCAT effects, noting that little or no effects are expected for some crash types (Table 5.1).

Table 5.1
DCA groupings by crash type

DCA Code	FCAT Crash Type
100-109,202-205	Intersection
301-303	Rear End
703,704,803,804	Hit Fixed Object
0-8	Pedestrian
201,501	Head On
700, 705-709	Loss of Control
305-309	Side Swipe
400-409	Manoeuvre
701,702	Off Path
600-610	Hit Object on Road
207,304	U-Turn
500,502	Overtake
900-907	Miscellaneous
300	Same Other
200	Opposite Other

The numbers of crashes involving light vehicles, by crash type, speed zone group and severity are shown in Table 5.2. Note that light vehicles cover all passenger vehicles including four-wheel-drive vehicles.

Table 5.2
Light vehicle crashes by crash type, speed zone group and severity

Crash Group	Speed Zones					
	50 and 60 km/h		70, 80 and 90 km/h		100 and 110 km/h	
	All injuries	Fatal	All injuries	Fatal	All injuries	Fatal
Head On	3,979	126	1,889	225	1,938	445
Hit Fixed Object	17,007	333	6,674	280	9,965	544
Hit Object On Road	1,139	8	718	7	884	17
Intersection	32,106	102	5,903	84	916	47
Loss Of Control	2,425	39	1,074	19	2,652	94
Manoeuvre	5,109	29	438	7	165	4
Miscellaneous	150	3	19	0	24	3
Off Path	517	0	416	4	1,800	48
Opposite Other	47	5	10	0	3	1
Overtake	361	7	120	10	275	21
Pedestrian	16,359	387	1,075	124	191	58
Rear End	25,357	27	9,211	21	2,036	19
Same Other	123	1	33	1	21	0
Side Swipe	3,352	7	1,433	20	581	13
U-Turn	1,572	2	271	4	189	11
Total	109,603	1,076	29,284	806	21,640	1,325

The numbers of crashes involving heavy vehicles by crash group, speed zone group and severity, are shown in Table 5.3. Heavy vehicles include all large rigid trucks, semi-trailers and similar vehicles.

Table 5.3
Heavy vehicle crashes by crash type, speed zone group and severity

Crash Group	Speed Zones					
	50 and 60 km/h		70, 80 and 90 km/h		100 and 110 km/h	
	All injuries	Fatal	All injuries	Fatal	All injuries	Fatal
Head On	85	12	68	12	168	42
Hit Fixed Object	228	5	210	11	622	52
Hit Object On Road	64	1	36	1	87	13
Intersection	425	11	201	19	80	13
Loss Of Control	211	7	171	15	590	28
Manoeuvre	118	7	29	1	35	5
Miscellaneous	18	0	1	1	4	1
Off Path	24	1	21	0	238	6
Opposite Other	3	0	1	0	0	0
Overtake	8	1	5	0	38	6
Pedestrian	304	52	51	23	40	25
Rear End	1,103	8	831	5	393	25
Same Other	7	1	5	0	5	2
Side Swipe	320	4	349	3	166	4
U-Turn	42	6	15	0	26	3
Total	2,960	116	1,994	91	2492	225

5.1.3 Selection of crashes for simulation

In order to select the most prevalent of the relevant crash types, proportions of injury crashes and fatal crashes falling into each DCA group were ranked by prevalence. Light and heavy vehicle crashes were considered separately. The top six categories were chosen, which covered approximately 90 percent of all crashes. Table 5.4 and 5.5 give the percentages; those DCA groups that are most relevant to FCAT systems are indicated by an asterisk.

Table 5.4
Percentage of light vehicle crashes represented by the DCA groups selected for simulation, by severity

Crash Group	Speed Zones					
	50 and 60 km/h		70, 80 and 90 km/h		100 and 110 km/h	
	All injuries	Fatal	All injuries	Fatal	All injuries	Fatal
Intersection*	29.3	9.5	20.2	10.4	4.2	3.5
Rear end*	23.1	-	31.5	2.6	9.4	-
Pedestrian*	14.9	36.0	3.7	15.4	-	4.4
Hit fixed object*	15.5	30.9	22.8	34.7	46.0	41.1
Loss of control	-	3.6	-	-	12.3	7.1
Manoeuvre	4.7	2.7	-	-	-	-
Side swipe	-	-	4.9	2.5	-	-
Head on*	3.6	11.7	6.5	27.9	9.0	33.6
Off Path	-	-	-	-	8.3	3.6
Total	91.2	94.4	89.4	93.5	89.2	93.3

Table 5.5
Percentage of heavy vehicle crashes represented by the DCA groups selected for simulation, by severity

Crash Group	Speed Zones					
	50 and 60 km/h		70, 80 and 90 km/h		100 and 110 km/h	
	All injuries	Fatal	All injuries	Fatal	All injuries	Fatal
Intersection*	14.4	9.5	10.1	20.9	-	5.8
Rear end*	37.3	6.9	41.7	5.5	15.8	11.1
Pedestrian*	10.3	44.8	-	25.3	-	11.1
Hit fixed object*	7.7	-	10.5	12.1	25.0	23.1
Loss of control	7.1	6.0	8.6	16.5	23.7	12.4
Manoeuvre	-	6.0	-	-	-	-
Side swipe	10.8	-	17.5	-	6.7	-
Head on*	-	10.3	3.4	13.2	6.7	18.7
Off Path	-	-	-	-	9.6	-
Total	87.5	83.6	91.8	93.4	87.4	82.2

These categories were used as a basis to select cases for simulation. A selection of crashes from CASR's in-depth crash investigation database was made to represent the circumstances of all crashes in the FCAT relevant categories.

At-scene crash investigation can provide a much more complete picture of the circumstances of a crash than is available in the mass crash data. CASR has been conducting such investigations for over four decades. However, the data used in this report was limited to investigations taking place between 1995 and 2011. During this time 1,145 cases were investigated, and of these cases, 364 had been reconstructed so that travel and impact speeds were known.

The objective was to simulate at least five cases from each individual combination of DCA code and speed zone group; however it was not always possible to identify suitable crashes to represent every relevant DCA code.

One possible reason that some DCA codes are commonly used in police data may be due to the sometimes limited information available to police when coding crashes. For example, DCA code 004, pedestrian playing, working, lying or standing on carriageway, is quite prevalent in the mass data though almost no such cases were seen in in-depth crash investigations. It may be that if police did not know which direction the pedestrian came from, this code was used, whereas in an in-depth crash investigation much more information is available and the movements of the pedestrian prior to impact are generally known. In-depth cases were lacking for some DCA codes due to difficulties in reconstructing them; for example crashes where the vehicle departs the road without losing control and strikes an object (these represent some of DCA 703,704, 803, 804).

In-depth cases involving heavy vehicles were not included in the analysis, as sufficient numbers of suitable crashes were lacking in the in-depth crash investigation database.

A total of 104 crashes were chosen for simulation. The number of cases in each crash type is given in Table 5.6. The cases are shown by the severity of the crash in Table 5.7; 21 were fatal crashes and the remaining 83 were injury crashes.

Table 5.6
Number of simulated cases by crash type and speed zone group

Crash Group	Speed zones		
	50 and 60 km/h	70, 80 and 90 km/h	100 and 110 km/h
Intersection	15	11	10
Rear end	8	1	2
Pedestrian	12	2	1
Hit fixed object	8	4	16
Head on	5	4	5
Total	48	22	34

Table 5.7
Number of simulated cases by crash severity and speed zone group

Crash Group	Speed zones		
	50 and 60 km/h	70, 80 and 90 km/h	100 and 110 km/h
Injury	44	15	24
Fatal	4	7	10
Total	48	22	34

5.1.4 Simulating the crash circumstances

In this project, extensive use was made of software called PreScan (Tass, Netherlands). PreScan is a simulation environment for primary safety technologies, and many types of sensor can be simulated, as can the response of a vehicle to sensor signals in many types of environmental conditions.

The trajectory, speeds, braking and impact configuration of the vehicles in the selected in-depth cases were modelled in PreScan. While PreScan is capable of performing very detailed simulations of advanced driver assistance systems, these capabilities were not used in this study. Rather, PreScan was used to generate a time based trajectory of the struck vehicle in the coordinates of the FCAT vehicle. This plot was then used as a basis for determining changes in closing speed with the inclusion of an FCAT system.

An example of how an in-depth crash investigation case was modelled in PreScan is shown in Figure 5.3. The site diagram from the crash is shown on the left and the scenario modelled in PreScan is shown on the right. The coloured lines in the PreScan diagram represent the trajectories of the vehicles with the spacing of the coloured symbols representing the speed of the vehicle.

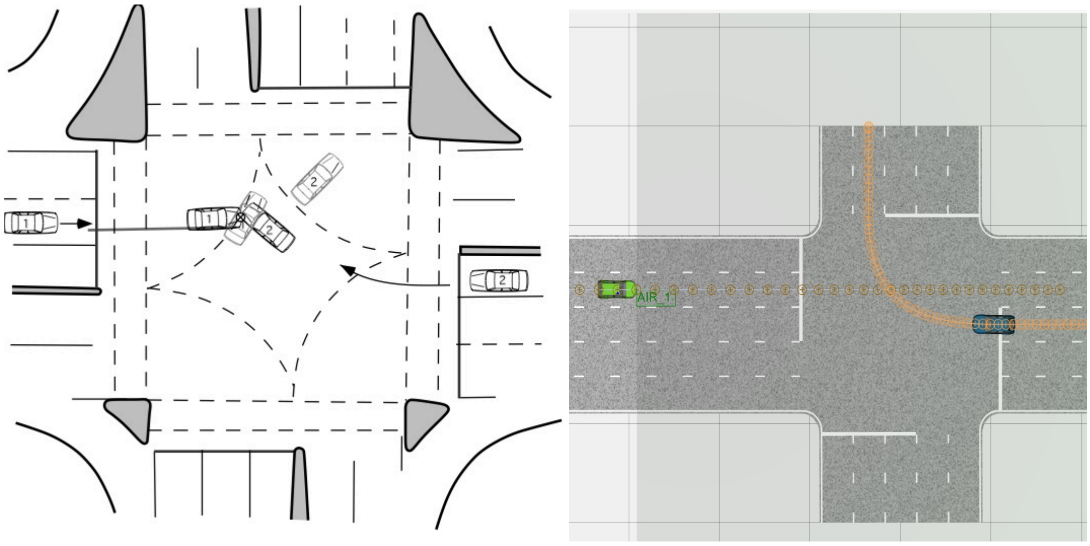

Figure 5.3
Site diagram of in-depth crash investigation case CN172 (left) and corresponding PreScan scenario (right)

The trajectory data produced by PreScan during the example above is shown in Figure 5.4. The longitudinal and lateral positions of the detected object over time are provided separately and can be combined to define the object trajectory.

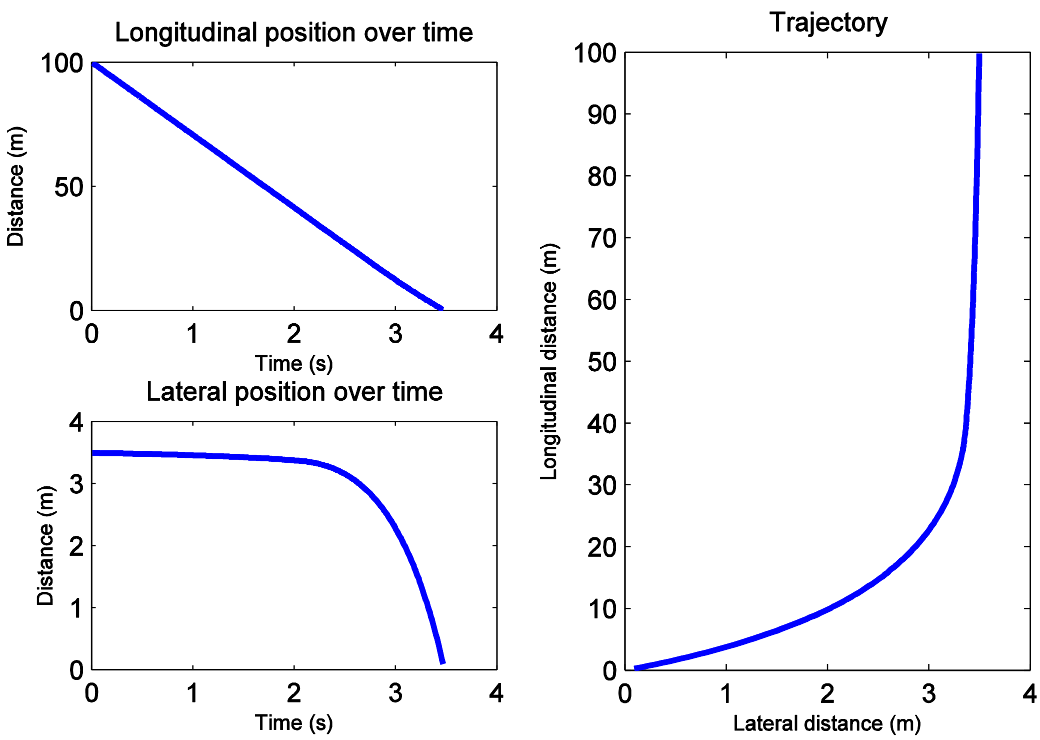

Figure 5.4
Trajectory data produced by PreScan for case CN172

5.1.5 Collision detection and intervention model

For each crash, the trajectory data was analysed to determine how the closing speed at the collision point might have been affected by an FCAT system. To do this, a generic FCAT system model was developed with several variable parameters. By varying these parameters, different FCAT systems were able to be represented, and their response during specific crash scenarios were modelled. The parameters, which are grouped into three categories, are discussed below. The operation of the model is then presented along with a discussion of the model limitations. Lastly, the parameter values that were used to represent several FCAT systems in the current project are shown.

Model parameters

Scan zone

The scan zone of an FCAT system defines the area, forward of the host vehicle, in which an object can be detected. Several technologies that make up the detection system in the FCAT systems were described in Section 4.1.

Typical detection systems scan a sector-shaped area ahead of the vehicle. However, some FCAT systems restrict the area to which they will react to an object in to a rectangle so as to ignore objects that are not directly in front of the vehicle.

In this study, the FCAT system model defined a scan zone using three attributes *scan shape*, *range* (in metres), and *angle/width* (in degrees/metres) as shown in Figure 5.5

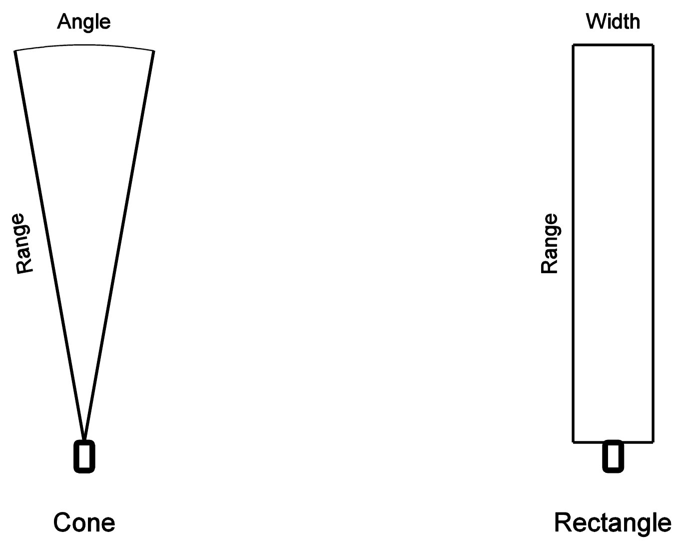

Figure 5.5
The two types of scan shape that can define the scan zone

Object tracking and collision detection

There are several ways in which FCAT systems detect and track objects. The technique used depends in part on the detection technology used. Furthermore, techniques may differ between systems that use similar detection technologies.

Some systems predict a collision based solely on the distance and relative speed of the object. Other systems use more sophisticated techniques to predict the future motion of objects based on their current position, speed, and acceleration.

The details of the object tracking and collision detection techniques are beyond the scope of this report but more information can be found in publications by Sun et al. (2006) and Geronimo et al. (2010).

For the FCAT system model, it was assumed that, within the scan zone, an object can be detected, tracked, and its future motion predicted with enough accuracy as to enable potential collisions to be identified.

The two attributes *computation time* and *prediction method* were used to define the characteristics of the model's object tracking and motion prediction ability. The *computation time* (in seconds) was used to represent the time required by the system to observe an object before its future motion can be successfully predicted. The *prediction method* then defines whether an advanced or simple motion prediction algorithm is used.

The advanced prediction method calculates the position of an object at t seconds into the future in both the longitudinal (x) and lateral (y) direction, based on the object's current position, velocity, and acceleration, as shown in the equations below (subscript i denotes the current longitudinal/lateral position, velocity, and acceleration and subscript f denotes the future longitudinal/lateral position).

$$x_f(t) = x_i + \dot{x}_i t + \frac{\ddot{x}_i t^2}{2}$$

$$y_f(t) = y_i + \dot{y}_i t + \frac{\ddot{y}_i t^2}{2}$$

The simple prediction method calculates the position of an object at t seconds into the future based on the object's current longitudinal (x) position and velocity, while ignoring the object's current lateral (y) motion, as shown in the equations below (subscript i denotes the current longitudinal/lateral position and velocity and subscript f denotes the future longitudinal/lateral position).

$$x_f(t) = x_i + \dot{x}_i t$$

$$y_f(t) = y_i$$

A potential collision is identified by calculating a future position that intercepts with the host vehicle. The FCAT system must then decide when to respond. The system cannot respond too early, as trajectories may change such that the collision is no longer likely. But the system must respond with enough time to reduce the severity of the collision. Lee and Peng (2005) detail some early collision warning and collision avoidance algorithms. In this study the FCAT system model uses a simple time to collision (TTC) value. The attribute *TTC action* (in seconds) defines at what length of time before a predicted collision the system will take braking action.

System response

Once an FCAT system has identified a potential collision there are many responses possible. ADAC (2011) tested six production passenger vehicles fitted with an FCAT system and tracked their warning and braking responses during an identical frontal collision scenario. All systems triggered a warning and then applied some level of final braking. However, the time at which the warning and braking were applied and the severity of the braking was different for each system. Additionally, some systems applied some level of partial braking between the warning and final braking.

In this study, the FCAT system model is designed to take braking action automatically once a potential collision has been detected within the *TTC action* time. It will also cooperate with the braking actions of the driver: if the driver brakes after a potential collision has been detected, then their deceleration is increased from the 0.7g that was used in the in-depth crash study reconstructions to a higher value.

The braking action of the model is defined by two attributes: *system deceleration* and *supported deceleration*. The *system deceleration* (in g) defines the amount of deceleration from braking the system applies automatically by itself. The *supported deceleration* (in g) defines the amount of deceleration from braking the system applies when the driver is pushing the brake pedal.

The resulting travelling speed at the collision point, as a result of the *system deceleration* and/or *supported deceleration*, is calculated as shown in the equation below, where S_f is the resulting travel speed, S_i is the initial travel speed, A is the deceleration value, and D is the distance over which the deceleration occurs.

$$S_f = \sqrt{S_i^2 - 19.62AD}$$

The resulting longitudinal closing speed can then be calculated by subtracting the difference between the initial travel speed and the resulting travel speed from the initial longitudinal closing speed.

Model operation

The operation of the FCAT model is explained diagrammatically in Figure 5.6. For an object to be successfully tracked, it must enter the scan zone defined by the *scan shape*, *range*, and *angle/width* attributes and must remain within the zone for a length of time specified by the *computation time* attribute. Once an object is being tracked it must stay within the scan zone in order for it to continue being tracked.

The future motion of the object is then predicted using an algorithm selected by the *prediction method* attribute. The system continuously updates the predicted future motion of the object and calculates whether the object is predicted to collide with the host vehicle in less than the time specified by the *TTC action* attribute. If the object is predicted to collide with the host vehicle within the *TTC action* time then a collision speed is calculated based on the system's braking response.

Three braking response scenarios are possible depending on the actions of the driver; the driver brakes before the FCAT system responds, the driver brakes after the FCAT system responds, or the driver does not brake at all.

If the driver brakes before the system responds, then the resultant travel speed at the collision point is calculated in two steps. A speed reduction is calculated using a deceleration of 0.7g over the distance between where the driver started braking and where the system responds. A further speed reduction is then calculated using the *supported deceleration* attribute value over the remaining distance to the collision point.

If the system brakes before the driver, then the resultant travel speed at the collision point is calculated in two steps. A speed reduction is calculated using the *system deceleration* attribute value over the distance between where the system responds and where the driver brakes. A further speed reduction is then calculated using the *supported deceleration* attribute value over the remaining distance to the collision point.

If the driver does not brake at all, then the resultant travel speed at the collision point is calculated using only the *system deceleration* attribute value over the distance from where the system responds to the collision point. The resulting longitudinal closing speed at the collision point is then calculated using the resultant travel speed.

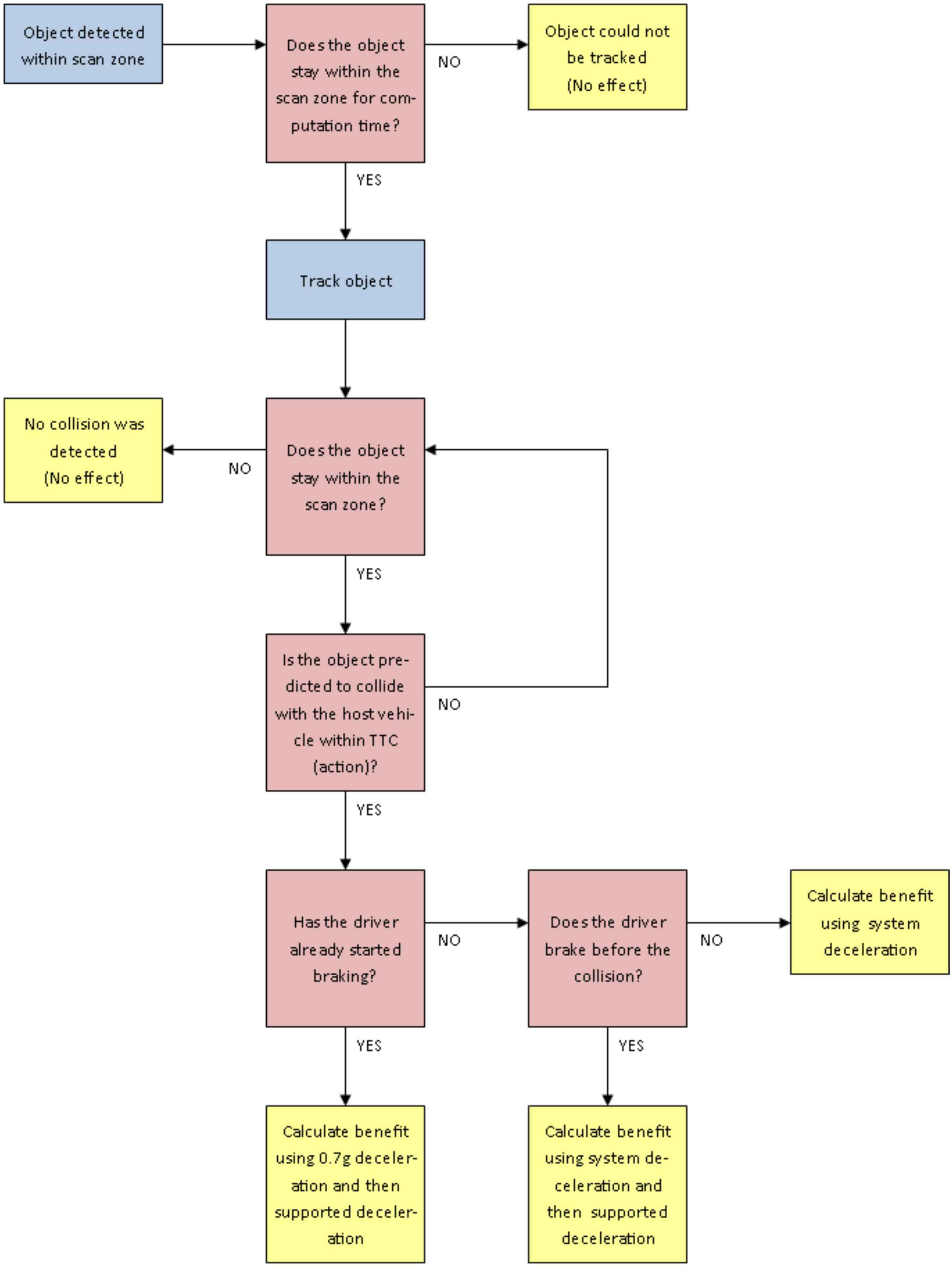

Figure 5.6
Flow diagram of FCAT system model

Model limitations

Apart from the assumptions mentioned above, and the usual limitations of simulating a real system with a model, the FCAT system model had two major limitations that should be noted.

The first was that the value for the *TTC action* attribute was static and did not adjust dynamically based on the conditions of the host vehicle. At faster travelling speeds the *TTC action* value should be increased to account for the increase in the time required to bring the host vehicle to a stop (or to a lower collision speed). This limitation is mitigated slightly by splitting the FCAT systems into long range and short range as shown below. The two categories of system are then provided with *TTC action* attribute values that are appropriate to the speed zone for which the system is designed.

The second major limitation is that no vehicle dynamics are taken into account once braking begins. That is, the model simply calculates the new travelling speed at the original collision point. What this does not take into account however is the change in vehicle relative trajectories as a result of FCAT system braking. Because of this the model cannot identify crashes where a change in trajectory prevents a collision from occurring. This is not relevant to hit fixed object crashes and is unlikely to be important for rear end, head on and pedestrian crashes. Intersection crashes where a vehicle is travelling across the path of another vehicle are most likely to be affected by this limitation. The current approach may therefore underestimate the effect of FCAT for this crash type.

Choosing model attribute values

Attribute values were selected to represent several FCAT systems as shown in Tables 5.8 and 5.9. The values for the attributes in each system were chosen based on published literature and the information provided by vehicle and FCAT manufacturers.

Typically, there are two distinct groups of FCAT systems; categorised here as ‘long range’ and ‘short range’. The long range systems evolved from, and built upon, adaptive cruise control (ACC) systems that are designed for high speed highway driving. ACC systems look ahead and match the speed of a leading vehicle but only operate when the speed difference between the host vehicle and leading vehicle is within a certain range. ACC systems are therefore of no assistance during driving scenarios with a large speed difference (e.g. if the lead vehicle suddenly brakes strongly). Long range FCAT systems build upon ACC by implementing additional software and hardware that enable the system to recognise the potential for a frontal collision and brake the host vehicle appropriately.

Table 5.8 shows the attribute values for the long range systems that were modelled. System A represents a generic long range system with a *TTC action* value of 2.0 seconds, partial *system deceleration*, and boosted *supported deceleration*. Systems B to E are variants of system A; system B has a greater *system deceleration*, system C has a shorter *TTC action* time, system D has a longer *TTC action* time, and system E has a wider scan zone *angle*.

Short range FCAT systems were designed to avoid or mitigate collisions during slower speed city driving, particularly with pedestrians. To avoid false alarms and ensure a fast response time, the scan zone is usually restricted to a rectangle in front of the host vehicle and a simple prediction method, which allows for a lower computation time, is used.

Table 5.9 shows the attribute values for the short range systems that were modelled. System F represents a generic short range system with a *TTC action* value of 1.0 second, partial *system deceleration*, and boosted *supported deceleration*. Systems G to J are variants of system F; system G has a greater *system deceleration*, system H has a shorter *TTC action* time, system I has a greater scan zone *width*, and system J uses a cone *scan shape* with an advanced *prediction method*.

Some high end FCAT systems are equipped with both long and short range capabilities. A system of this type was modelled by considering the best outcome from system B and system J.

Table 5.8
Attribute values for various long range systems

Attribute	System A	System B	System C	System D	System E
Scan shape	Cone	Cone	Cone	Cone	Cone
Range (m)	100	100	100	100	100
Angle/width (deg/m)	15	15	15	15	20
Computation time (s)	0.2	0.2	0.2	0.2	0.2
Prediction method	Advanced	Advanced	Advanced	Advanced	Advanced
TTC action (s)	2.0	2.0	1.5	3.0	2.0
System deceleration (g)	0.4	0.8	0.4	0.4	0.4
Driver supported deceleration (g)	0.8	0.8	0.8	0.8	0.8

Table 5.9
Attribute values for various short range systems

Attribute	System F	System G	System H	System I	System J
Scan shape	Rectangle	Rectangle	Rectangle	Rectangle	Cone
Range (m)	40	40	40	40	40
Angle/width (deg/m)	4	4	4	5	40
Computation time (s)	0.1	0.1	0.1	0.1	0.2
Prediction method	Simple	Simple	Simple	Simple	Advanced
TTC action (s)	1.0	1.0	0.8	1.0	1.0
System deceleration (g)	0.6	0.8	0.6	0.8	0.6
Driver supported deceleration (g)	0.8	0.8	0.8	0.8	0.8

A comparison of the various scan zones for each of the modelled FCAT systems in shown in Figure 5.7 and a visual example of the FCAT models response is shown in Figure 5.8.

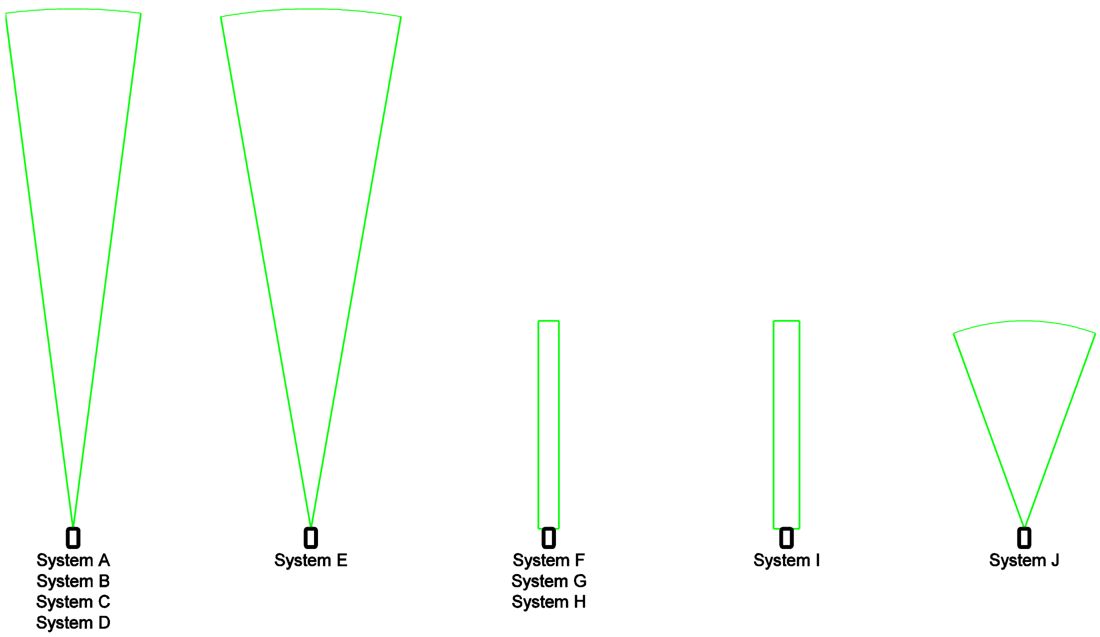

Figure 5.7
Comparison of scan zones for each of the FACT model systems

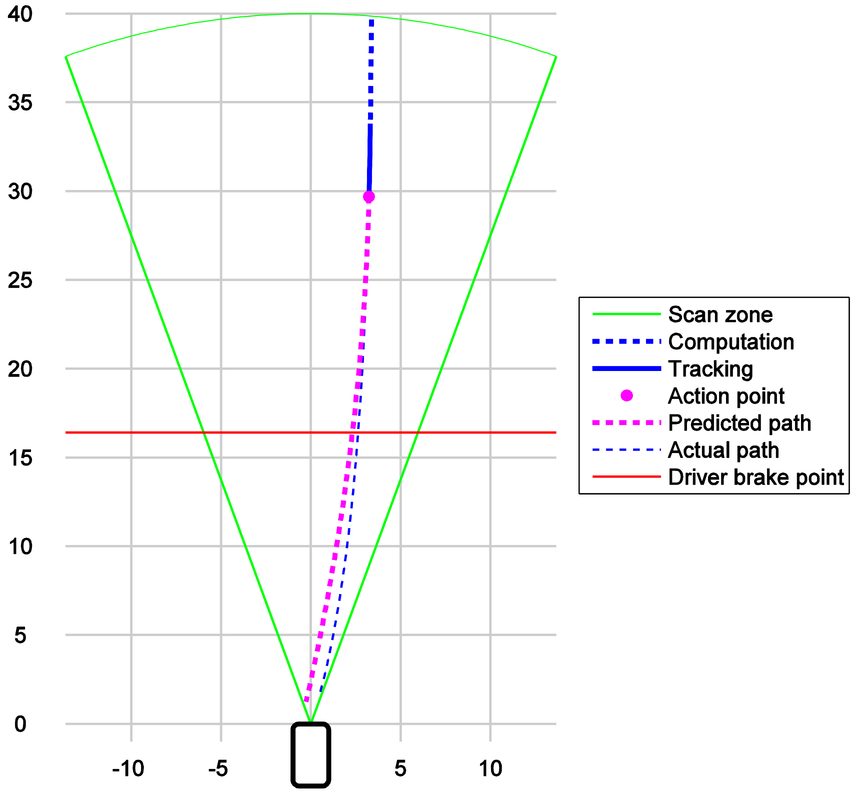

Figure 5.8
FCAT model response to in-depth crash investigation case CN172 (c.f. Figure 5.3 and Figure 5.4); the action point precedes the driver brake point resulting in a reduction in impact speed

5.1.6 Injury risk analysis

For the purpose of examining the benefit of FCATs, the probability, or risk, of injury or death at various speeds was considered with respect to the actual crash injury outcome.

Injury categories

Within the NSW mass data there are three categories for degree of crash; fatal, injury or no injury, where injury is any level of injury without consideration of severity.

The CASR in-depth crash studies include several levels of injury severity. These levels are:

- No injury
- Minor injury (no ambulance transport)
- Transport to Hospital (no hospital treatment)
- Hospital Treatment (treatment of casualty without hospital admission)
- Hospital Admission (treatment exceeds 4 hours)
- Fatality (death resulting form crash occurs within 30 days of crash)

For comparison with the NSW crash database, the CASR in-depth crash study injury severities were reduced to three injury groups consistent with the NSW database's 'degree of crash'. Table 5.10 shows the different definitions for injury as used in this analysis.

Table 5.10
Categories of injury severity

NSW Degree of Crash	CASR In-depth Crash Severity	MAIS Severity	MAIS Description
No Injury	No Injury, Minor Injury (No Ambulance Transport)	MAIS 0 - 1	No injury - Minor injury
Injury	Ambulance Transport, Hospital Treatment/Admission	MAIS 2 - 5	Moderate - Critical Injury
Fatal	Fatal	Fatal	Fatal

MAIS 1 was grouped with MAIS 0 for the purpose of this analysis as 'no injury', as it was assumed to correspond most closely with a no-injury crash in the NSW mass database.

Vehicle speed and injury risk

Several studies have attempted to relate crash vehicle impact speed or delta-v to risk of occupant or pedestrian injury in the form of a speed-injury risk relationship.

Vehicle speed and injury to vehicle occupants

NHTSA (2005) included an analysis of the risk of occupant injury or fatality in crashes from 1995-1999, "for all passenger vehicle occupants involved in crashes where at least one passenger vehicle used brakes". NHTSA (2005) derived individual probability risk functions for MAIS 0, MAIS 1+, MAIS 2+, MAIS 3+, MAIS4+, MAIS 5+ and fatal injuries.

The NHTSA injury probability risk functions were chosen for the analyses as they were considered the most appropriate model for the particular analysis. Using the NHTSA delta-v injury risk functions for MAIS 0-1, MAIS 2-5 and fatal, risk curves were generated for these injury categories consistent with the definitions in Table 5.10

Figure 5.9 shows the absolute risk of a particular injury (relative to the other injuries), adapted from NHTSA (2005) for the three defined injury categories. This presentation of the risk curves considers the individual risks of MAIS 0-1, MAIS 2-5 and fatality at each delta-v as a proportion of 100 per cent. For example, the risk at a delta-v of 0 km/h of MAIS 0-1 is 100 per cent, and zero for MAIS 2-5 and fatal injuries respectively. At a delta-v of 50 km/h the risk of a MAIS 0-1 is 45 per cent, the risk of MAIS 2-5 is 52 per cent, and the risk of a fatal injury is three per cent.

This graph can also be drawn as a cumulative risk of injury as shown in Figure 5.10. According to Figure 5.10 at a delta-v of 50 km/h the cumulative risk of a fatality is three per cent, the cumulative risk of fatality or injury (MAIS 2+) is 55 per cent, which is the sum of the individual risks for fatality and injury at the delta-v of 50km/h.

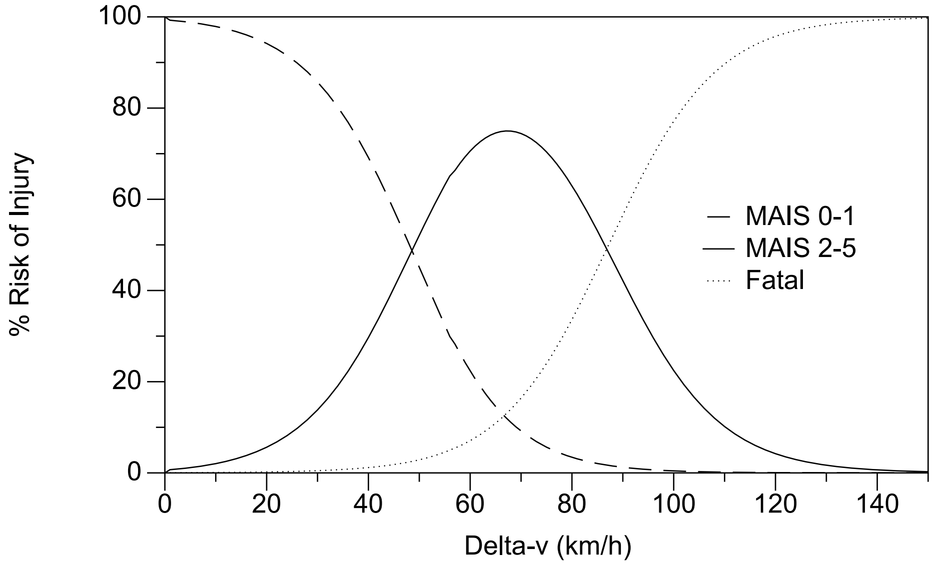

Figure 5.9
Maximum occupant injury risk curves adapted from NHTSA (2005), for MAIS 0-1, MAIS 2-5 and fatal injuries.

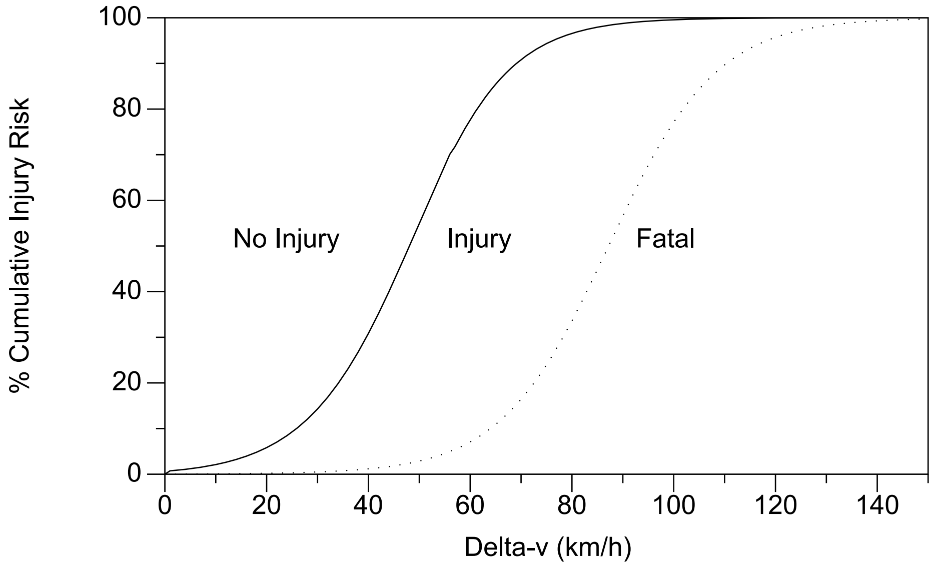

Figure 5.10
Cumulative occupant injury risk curves derived from NHTSA (2005), showing the proportion of no injury, injury and fatal at each delta-v.

Vehicle speed and injury to pedestrians

Rosen (2009), considered German Crash Data (GIDAS) from 1997-2007, resulting in a total sample of 490 pedestrian crashes and 36 fatalities for pedestrian aged 15 years and over. Rosen (2009) developed a risk function for vehicle impact speed and risk of fatality.

Davis (2001) derived similar risk curves by analysing crash data from previous studies. Additionally, he generated injury risk functions for slight, serious and fatal collisions. Although the crash data is older than that from Rosen (2009) these injury risk functions were selected for the analysis, as it is able to represent the risks of the three injury levels considered in this analysis.

Note that the fatal risk curve from Rosen (2009) correlates reasonably well with the fatal risk curve from Davis (2001), particularly for impact speeds less than 60km/h.

Figure 5.11 shows the absolute risk of injury for the three defined injury categories from Davis (2001). This graph can also be drawn as a cumulative risk of injury as shown in Figure 5.12.

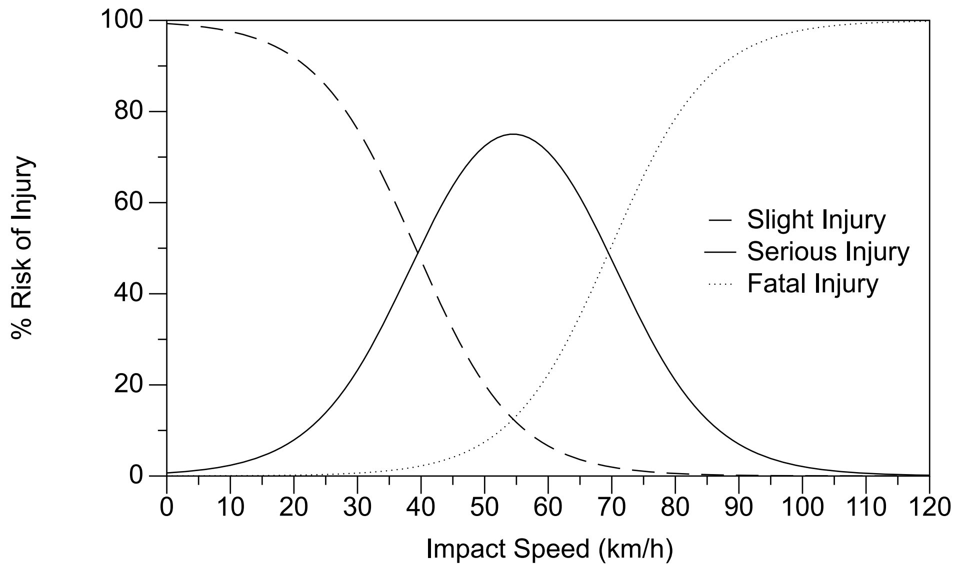

Figure 5.11
Pedestrian collision risk curves from Davis (2001), for slight injury, serious injury and fatal injury.

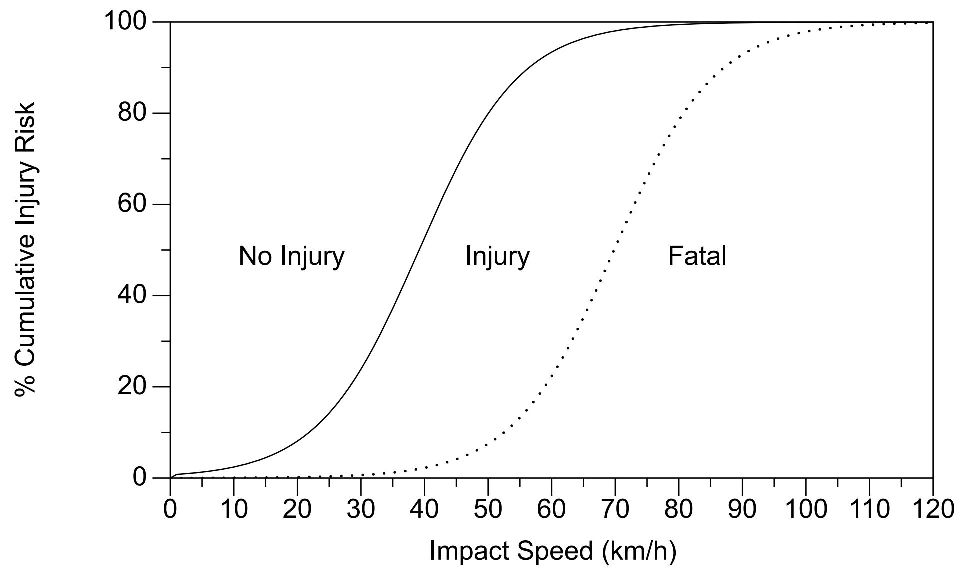

Figure 5.12
Cumulative pedestrian injury risk curves adapted from Davis (2011), showing the proportion of no injury, injury and fatal at each impact speed.

Determining injury risk based on speed modification

Pedestrian injury risk is presented as a function of the vehicle impact speed, which is the velocity of the vehicle relative to the velocity of the pedestrian, immediately prior to the collision.

Vehicle occupant injury risk is posed in terms of delta-v. The delta-v is a function of the closing speed, the masses of both vehicles and the coefficient of restitution in the collision. As the FCAT model determines a longitudinal closing speed, a general relationship between delta-v and longitudinal closing speed was used to estimate the delta-v that would be produced in each relevant crash scenario.

From the CASR in-depth crash studies, the individual speed reconstructions yield a longitudinal closing speed and a corresponding delta-v. Considering a number of crash configurations and generalising, the relationships for delta-v and longitudinal closing speed were derived as shown in Table 5.11.

Table 5.11
Estimated relationship between longitudinal closing speed and delta-v

CASR In-depth Crash Type	Delta-v Functions
Head-on collisions	Delta-v = 0.5 x closing speed
Hit fixed object	Delta-v = closing speed
Intersection	Delta-v = 0.6 x closing speed
Rear End	Delta-v = 0.6 x closing speed

Determining crash injury outcomes with FCAT

The process for determining the effect of an individual FCAT type on risks of a poor crash outcome is as follows:

For the no-FCAT case (original crash)

- The actual crash closing speed was converted to a delta-v according to Table 5.11 (no adjustment for pedestrian crashes).
- The probability of fatality, injury or no injury was determined from the appropriate risk functions.

For the FCAT case

- The new closing speed was adjusted according to Table 5.11 (no adjustment for pedestrian crashes).
- The probability of fatality, injury or no injury was determined from the appropriate risk functions for the revised delta-v, given the original severity of the crash.

To determine new risks, given FCAT speed reductions, the crash severity was “redistributed” into the probabilities of the crash being in the original severity category or a lower category, according to the risk curves and the new and original speeds.

If the FCAT system has no effect on the vehicle closing speed, then the predicted injury outcome is the same as the original injury outcome. If the FCAT system reduces the closing speed then the following process was applied.

For a crash where the outcome was an injury, the injury risks are found by equations 1 and 2. The definitions for the variables used are shown in Table 5.12.

$$P_{FCAT\ Speed}\ (injury|crash\ was\ injury) = \frac{1 - P_{crash\ speed}(fatal) - P_{FCAT\ Speed}(none)}{P_{crash\ speed}(injury)} \quad (1)$$

$$P_{FCAT\ Speed}\ (none|crash\ was\ injury) = 1 - P_{FCAT\ Speed}\ (injury|crash\ was\ injury) \quad (2)$$

In some cases, an FCAT system can produce a probability that no injury would occur. This occurs when the FCAT speed has been reduced to zero and the collision is theoretically avoided or when:

$$P_{FCAT\ Speed}\ (none) > 1 - P_{crash\ speed}(fatal)$$

In these cases, the injury is redistributed completely to no injury (none).

Table 5.12
Nomenclature for Equations

Risk Function Predictors	Crash Speed	FCAT Speed
Probability of no injury	$P_{crash\ Speed}\ (none)$	$P_{FCAT\ Speed}\ (none)$
Probability of slight/serious injury	$P_{crash\ Speed}\ (injury)$	$P_{FCAT\ Speed}\ (injury)$
Probability of Fatal	$P_{crash\ Speed}\ (fatal)$	$P_{FCAT\ Speed}\ (fatal)$

For example, consider a scenario where an injury resulted from a single vehicle that crashed with a delta-v of 60 km/h. At a delta-v of 60 km/h the injury risk curve in Figure 5.10 predicts a risk of injury in the crash ($P_{60}(injury)$) to be 70.6 per cent. Figure 5.14 shows the individual no injury, injury and fatal predicted distributions at 60km/h. The 70.6 per cent injury risk is depicted by the $P_{60}(injury)$ interval in the injury area of Figure 5.13. Now consider the effect of an FCAT system that reduces the delta-v of the vehicle to 50 km/h. The predicted injury distributions are shifted, as indicated in Figure 5.13, and the injury is redistributed according to equation 1 and 2, as shown in Figure 5.14.

$$P_{50}(injury|crash\ was\ injury) = \frac{1 - P_{60}(fatal) - P_{50}(none)}{P_{60}(injury)} = \frac{1 - 0.071 - 0.45}{0.71} = 68\%$$

$$P_{50}(none|crash\ was\ injury) = 1 - P_{50}(injury|crash\ was\ injury) = 1 - 0.68 = 32\%$$

As a result, the injury has been redistributed to 0.68 injuries and 0.32 no injuries.

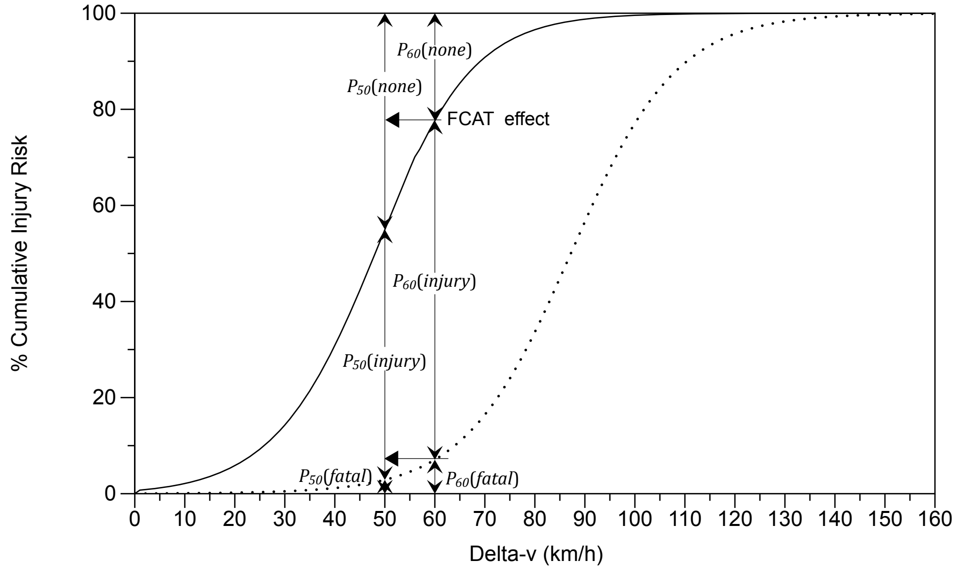

Figure 5.13
An example of the redistribution of an injury from a delta-v of 60km/h to an FCAT reduced delta-v of 50km/h

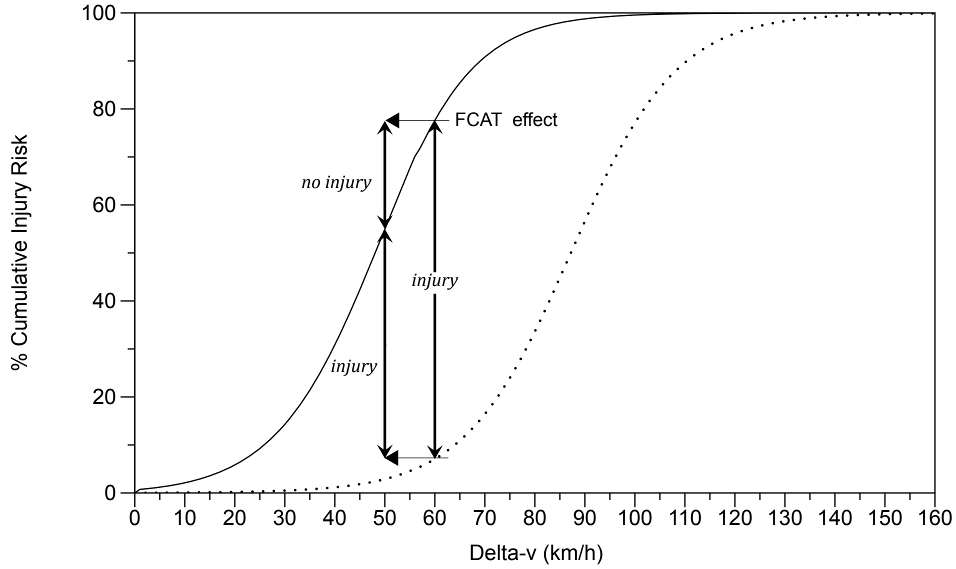

Figure 5.14
The injury from a crash delta-v of 60km/h to an FCAT reduced delta-v of 50km/h has been redistributed to injury and no injury.

In the case of a fatal crash, the severity is also redistributed based on the predicted risks (at the actual crash delta-v and the FCAT reduced delta-v); in the majority of cases, the fatality is re-distributed into probabilities of fatal and injury outcomes according to equation 3 and 4.

$$P_{FCAT\ Speed}\ (fatal|crash\ was\ fatal) = \frac{P_{FCAT\ Speed}(fatal)}{P_{crash\ speed}(fatal)} \tag{3}$$

$$P_{FCAT\ Speed}\ (injury|crash\ was\ fatal) = \frac{P_{crash\ speed}(fatal) - P_{FCAT\ Speed}(fatal)}{P_{crash\ speed}(fatal)} \tag{4}$$

Consider a scenario where a fatality resulted from a single vehicle that crashed with a delta-v of 80 km/h. Figure 5.15 shows the no injury, injury and fatal predicted distributions at 80km/h. At a delta-v of 80 km/h, the fatality risk according to Figure 5.9 is 33.6 per cent. This 33.6 per cent fatality risk is depicted by the $P_{80}(fatal)$ interval in the fatal area of Figure 5.15. Consider now the effect of an FCAT system that reduces the delta-v to 60 km/h. The predicted no injury, injury and fatal distributions are shifted, as indicated in Figure 5.15, and the fatality is redistributed according to equation 3 and 4 and shown schematically in Figure 5.16.

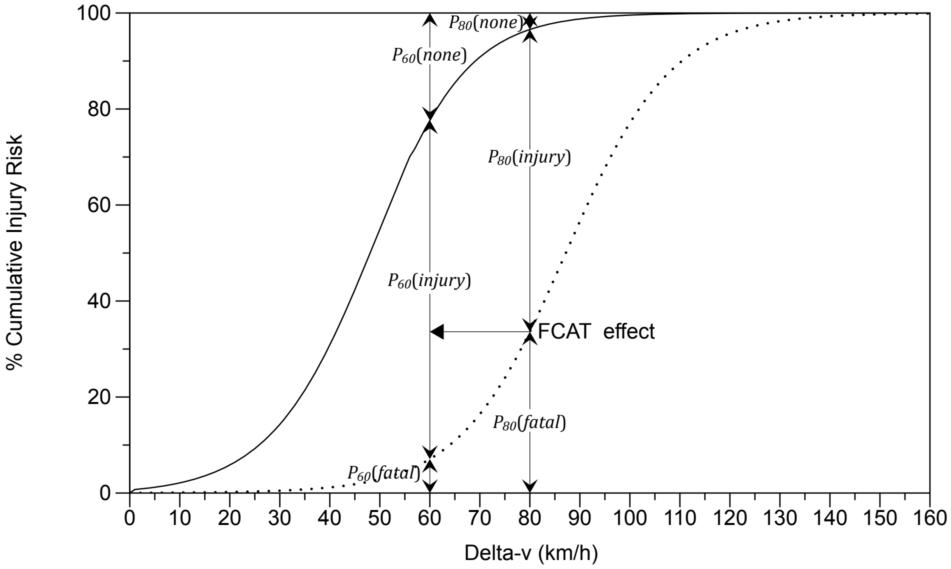

Figure 5.15
An example of the redistribution of a fatality from a crash speed of 80km/h to an FCAT reduced speed of 80km/h.

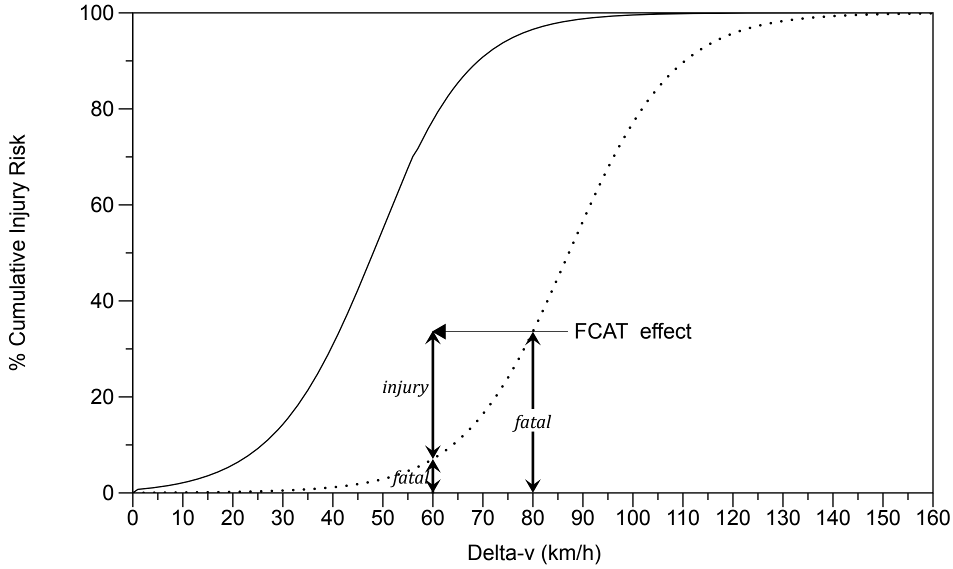

Figure 5.16
The fatality from a crash delta-v of 80km/h to an FCAT reduced crash delta-v of 60km/h has been redistributed to fatality and injury.

Then according to equation 3 and equation 4.

$$P_{60}(fatal|crash\ was\ fatal) = \frac{P_{60}(fatal)}{P_{80}(fatal)} = \frac{0.071}{0.336} = 21\%$$

$$P_{60}(injury|crash\ was\ fatal) = \frac{P_{80}(fatal) - P_{60}(fatal)}{P_{80}(fatal)} = \frac{0.336 - 0.71}{0.336} = 79\%$$

The risk redistribution results in 0.21 fatalities and 0.79 injuries.

In some cases, an FCAT system can produce a probability that no fatality or injury would occur. This occurs when the FCAT speed has been reduced to zero and the collision is theoretically avoided. In some cases a fatality is redistributed as a fatality, injury and no injury, this occurs when:

$$P_{FCAT\ Speed}\ (none) > 1 - P_{crash\ speed}(fatal)$$

In this case equation 5 replaces equation 3 and equation 6 is used to calculate the probability of no injury.

$$P_{FCAT\ Speed}\ (injury|crash\ was\ fatal) = \frac{P_{FCAT\ Speed}\ (injury)}{P_{crash\ speed}(fatal)} \qquad (5)$$

$$P_{FCAT\ Speed}\ (none|crash\ was\ fatal) = \frac{P_{crash\ speed}(fatal) - P_{FCAT\ Speed}(fatal) - P_{FCAT\ Speed}\ (injury)}{P_{crash\ speed}(fatal)} \qquad (6)$$

This process was applied to each individual crash and for each individual FCAT system. The individual probability outcomes in each crash were then averaged for each particular crash type and speed zone group.

Limitations

The risk curves used refer to a vehicle-based measure of severity, whereas we have used them to indicate severity in a crash. Theoretically, it might be appropriate to adjust the risk curves accordingly. The more units involved in a crash, the greater the likelihood that the severity will be higher due to random effects. However, no adjustment was made on the following grounds:

- In at least half of injury crashes and in the majority of fatal 2-car crashes, the outcome is asymmetrical and a single unit determines the severity. No adjustment is necessary in these cases.
- Adjusting the risk curves would have inflated the risks in multi-unit crashes. Given the curves are based on injury outcomes in much older vehicles (circa 1990), we felt that any adjustment that would inflate the risks would be over-stating risks in a future fleet of vehicles.

5.1.7 Benefit – cost analysis

Having described the method for estimating changes in risk for each crash type, we now describe the method to convert these to the potential benefit of FCAT systems arising from reduced crash severity and incidence. The starting point is the estimated average involvement of passenger vehicles and heavy vehicles in relevant crash types. In order to estimate potential reductions in crash involvement, changes in risk are applied. The changes in risk are those estimated from the simulation of individual crashes, as described above. In that analysis, the effect of various FCAT systems on impact speeds was determined in 104 crashes through detailed reconstruction of crash trajectories, and these were then converted to estimates of changes to injury risk.

In order to estimate average involvement of a vehicle in crashes, historical crash data are analysed and the results used to impute the number and timing of relevant crashes over a vehicle's life. Importantly, these estimates are made for individual vehicle cohorts, each cohort corresponding to a year of manufacture. Imputed crash involvement rates are calculated for historical vehicle cohorts, and the trend in these imputed values is used to project future crash involvement rates of cohorts of vehicles manufactured from 2010 to 2020.

The imputed crash involvement rates were then multiplied by the average change in risk by crash type and speed zone. From these individual changes in risk, an aggregate change in risk was assembled. It was then straightforward to monetise the reduction in crash involvement. The potential benefits of FCAT systems are monetised using accepted values indicating the willingness to pay to avoid fatal and injury crashes.

The methodology is outlined in Figure 5.17.

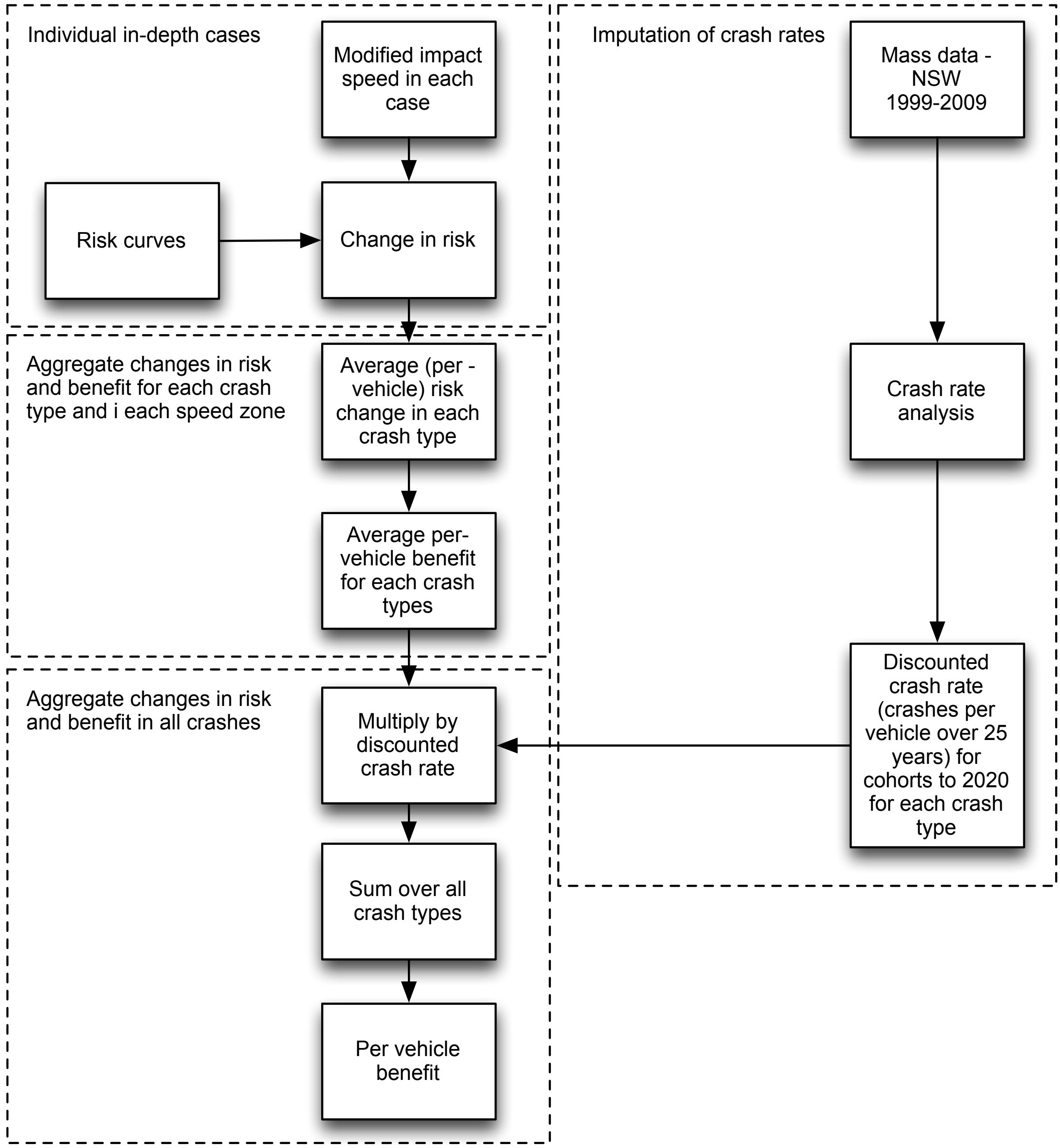

Figure 5.17
Flow chart outlining the methodology employed to estimate the benefit of FCAT systems

Imputation of crash rates

The procedure to calculate the benefits of a vehicle safety technology consists of estimating the rate of crash involvement (per vehicle, of the relevant kind of crash) and to multiply this by the reduction in risk and the costs of the crashes avoided. The product is the monetised benefit of the technology. Therefore it is necessary to estimate the per-vehicle rate of the crashes that are likely to be reduced by FCAT systems.

It is normal practice to discount future crash costs. Typically, either a constant per-period crash rate is assumed or else, the average per-vehicle crash rate needs to be estimated for each age of vehicle.

The latter method is to be preferred, as it allows a better estimate of future crashes for a given cohort and crash type, and hence more meaningful present value crash costs to be calculated.

The per-vehicle crash rate of a cohort of vehicles manufactured in a specific year will depend on several factors

- The age of the vehicle (from factors including vehicle use and average driver characteristics that might vary with vehicle age),
- The period being considered (from factors including prevailing average speeds, levels of compliance, changes to roads), and
- Characteristics of the cohort of vehicles themselves (from factors related to the design and performance of the vehicle, particularly the improved crashworthiness of vehicles)

Separating these three effects from crash data is difficult, as the age of the vehicle is the difference between the crash year (the period) and the year that the vehicle was manufactured (the cohort).

In this study, the approach was to use information in historical crash data to estimate the proportion of crashes in each crash type that occur in each year of a cohort's life. The total crash involvement is also calculated. These data may be used as raw estimates of crash involvement and further, used to calculate discounted estimates of crash involvement. Trends in the total rate of crash involvement indicate what the rate of crash involvement might be in future cohorts of vehicles, accounting for other trends in road safety and vehicle improvements.

The analysis uses eleven years of crash data from New South Wales (1999-2009) to establish the average distribution of crashes across vehicle ages. These were converted to crash involvement rates using Australian Bureau of Statistics (ABS) data, made available as part of their annual motor vehicle census (ABS, 2011), to estimate the size of each vehicle cohort.

The crash data contain fragments of the time series of crashes occurring to several cohorts of vehicles (for example, they contain the crash history for the first 11 years of the 1999 cohort of vehicles, the first three years of the 2007 cohort of vehicles and years nine to 20 of the 1990 cohort). These fragments are used to build a crash history profile for any given cohort and for any given crash type.

Data made available by the ABS provides the size of each cohort in successive years. The pattern is that a cohort only reaches its maximum size in census taken two years after the cohorts 'birth' (the census is taken near the start of a year). The size of each cohort in this year was used to represent the population in the cohort.

As the study uses crash data from New South Wales, it is likely that the crash experience of vehicles sold in New South Wales is not completely captured by an analysis of New South Wales crash data. New South Wales is a net exporter of second-hand vehicles to other states of Australia, and so crashes experienced by those vehicles exported interstate will not be recorded in New South Wales crash data. Consequently, part of the method deals with adjustments to the crash data to account for this. The details of how the crash data were adjusted are contained in Appendix B.

To construct an estimate of the average distribution of crashes over each cohort's life, the change in crash rate in each cohort from one year to the next was calculated and averaged over all cohorts. This average change in crash numbers from one age to another was then used to compute the average age distribution of vehicles in each crash type.

To illustrate, the change in the rate of crashing from one year to the next was calculated for all crash types. The average 'crash rate change function' is shown in Figure 5.18. A negative number on the yaxis indicates a reducing number of crashes from one year to the next, and a positive number indicates an increasing number of crashes from one year to the next.

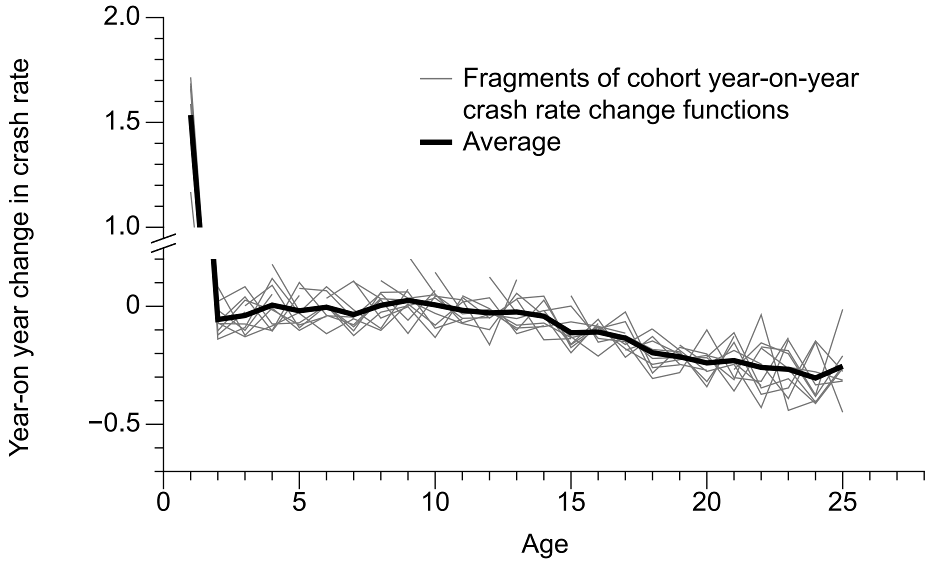

Figure 5.18
Year on year changes in crash numbers in vehicle cohorts represented in crash data for years 1999-2009, and the smoothed average of all ages for which data were available.

The line that represents the average change in crash numbers can now be used to construct an average crash distribution, assembled from all cohorts of vehicles in the crash data. Further, this distribution can be discounted to reflect the discounted cost of the crashes later in a vehicle's life. The resulting distributions for the data are shown in Figure 5.19. (In this case, a rate of three per cent has been applied to derive the discounted distribution.)

As mentioned above, the crash data used for this study covers the years 1999-2009, and as such contains only fragments of each cohorts crash history. However, given an estimate of the average year-on-year change in crash numbers across all of the fragments, the crash history of any given cohort can be imputed by fitting the average crash distribution (for example, as shown in 5.20) to the data that exists for the cohort, and allowing the remainder of the fitted distribution to be an imputation of the unknown crash history of the cohort. In this way, we can estimate the number and timing of crashes of vehicles presently in the fleet, into the future.

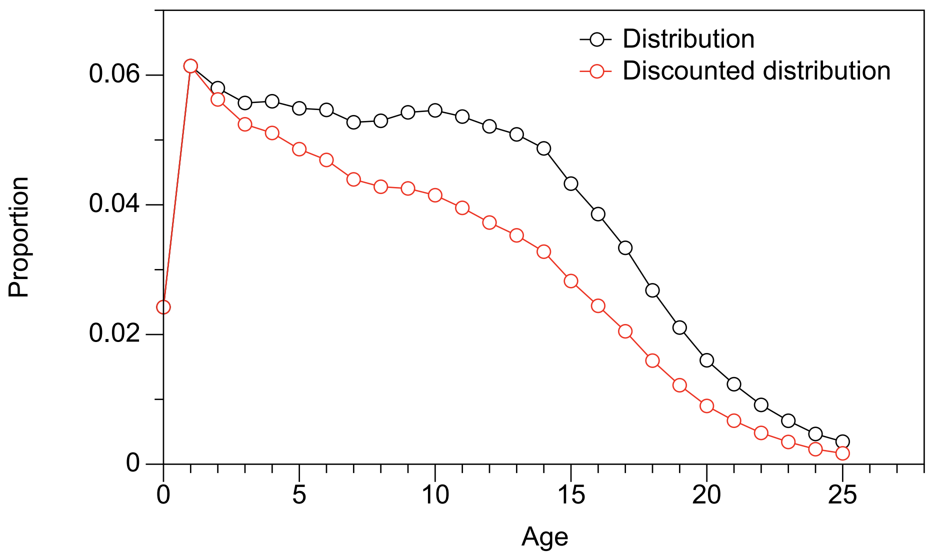

Figure 5.19
Injury crash distribution over age of a vehicle cohort in New South Wales based on the average year-on-year changes in crash numbers across vehicle cohorts in crash years 1999-2009. Proportion expressed is of crashes within the first 25 years of life. The discounted distribution uses a discount rate of three per cent.

The resulting crash rate of each cohort and the trend in the total are shown in Figure 5.20. Similar results were obtained for fatal crashes, noting that the imputed crash rate for the 2009 cohort has been omitted as it is based on a very small number of crashes (Figure 5.21).

It is worth noting that the declining crash rate over cohorts is a combination of cohort effects (i.e. attributable to year of manufacture) and period effects (i.e. attributable to the period in which crashes within a given cohort occur).

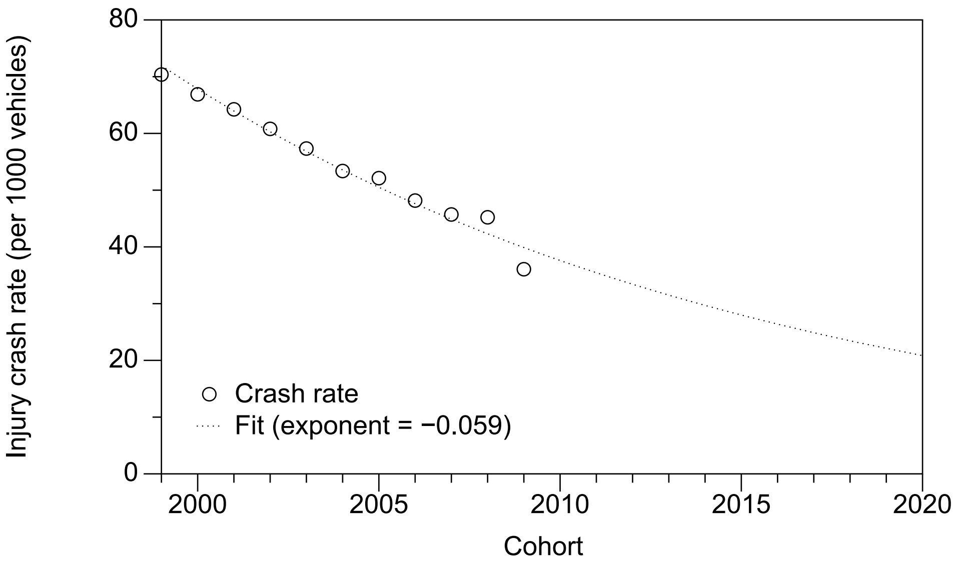

Figure 5.20
Injury crash rate of vehicle cohorts over the first 25 years of life, estimated for vehicles built from 1999 to 2009 and a projection to 2020.

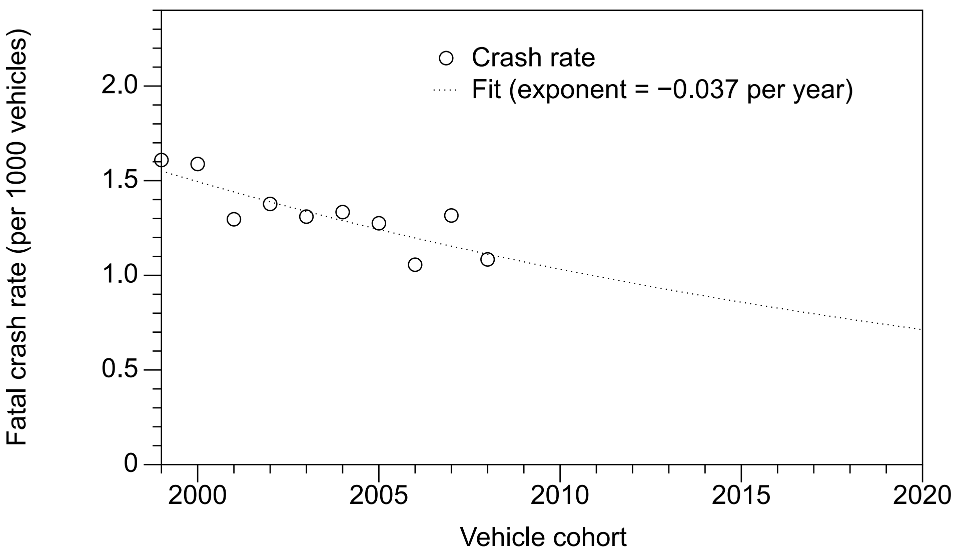

Figure 5.21
Fatal crash rate of vehicle cohorts over the first 25 years of life,
estimated for vehicles built from 1999 to 2009 and a projection to 2030.

The projection of the total crash rate, as illustrated above, can be used to create a distribution of crashes over the life of a future cohort of vehicles. Having done so, it is straightforward to discount the distribution in the usual manner and sum the associated crash costs. In this study, the total costs discounted over the first 25 years of a vehicle's life were used to characterise crash costs.

The procedures described above were repeated on the crash data disaggregated into the crash types and speed zones described in Section 5.1.2, so that the probability that any vehicle would be involved in a particular type of crash could be estimated. Benefit estimates were therefore able to be aggregated from the estimated benefit in individual crash types and speed zones, thereby allowing for variation in effectiveness across crash types.

Crash costs

For the purposes of monetising crash costs, crash costs were taken from The RTA Economic Assessment Manual (Appendix C - Economic Parameters for 2009; RTA, 2009). In this study willingness to pay estimates are used, and have been indexed by 2.5 per cent per annum so that they can be expressed in 2012 dollars. The rates for monetising crashes were $6,283,000 per fatal crash and $123,000 per injury crash. Property damage only crashes are not explicitly examined in the report, but note here the average cost is about $9,000 per crash.

Non-fatal crashes are under-reported to police. The Bureau of Transport and Regional Economics (BITRE) estimates give the number of crashes in New South Wales for 2006 (Anderson *et al.*, 2011): 449 fatal crashes and 69,827 injury crashes. CrashLink data give the numbers as 449 fatal crashes and 19,640 injury crashes suggesting a gross under-reporting of injury crashes. At the time of writing it was not clear whether the willingness-to-pay cost of an injury crash given by the RTA Economic Manual have been adjusted to take account of this under-reporting. Clearly, inflating the per-police reported crash cost by a factor of more than three will have a large effect on the benefit calculations. At this stage, no adjustment has been made to the injury crash costs on the basis that the use of RTA crash costs with RTA crash statistics provide an internally consistent estimate of benefits that might be compared with other safety programs that have used the same figures.

5.2 Results

5.2.1 Injury risk analysis

Each FCAT system modelled produced a new collision speed for each individual crash simulated (though in some cases this new collision speed was identical to the original collision speed). This collision speed was adjusted to give a new delta-v. Figure 5.22 displays the cumulative distribution of these new delta-v for the baseline long range system (A), baseline short range system (F) and the combination system (B+J). The original delta-v distribution is also displayed. The early rise of the distributions of delta-v with an FCAT system, relative to the original distribution indicates that the delta-v is more likely to be low. The distributions of the collision speed with an FCAT system do not reach one because some crashes are avoided all together.

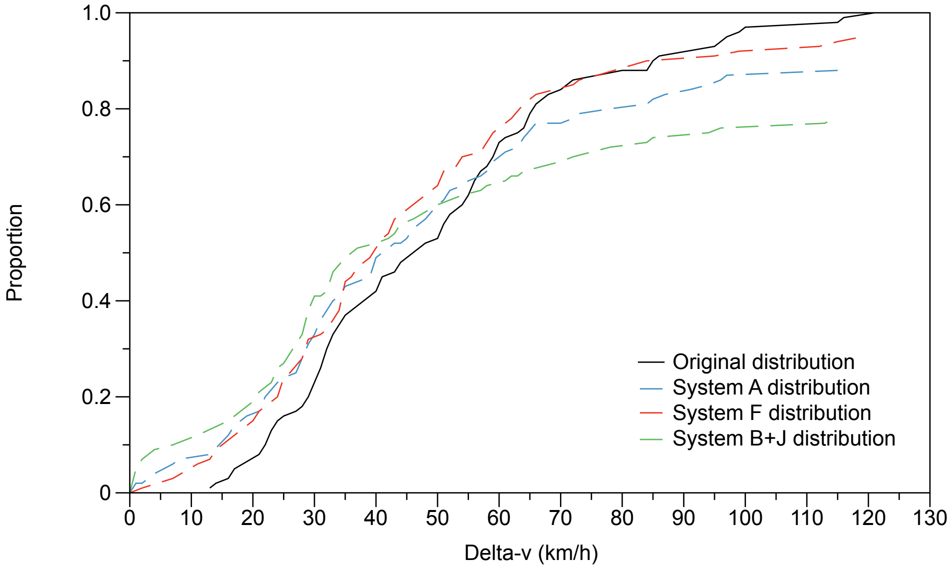

Figure 5.22
Cumulative distribution of collision speeds in the 104 crashes simulated, and the distribution with selected FCAT systems applied. Note that collisions avoided are represented by distributions that accumulate to less than one.

Changes in risk were calculated for all systems specified. The average changes in risk are given in Table 5.13. Note that in the case of 50/60 km/h hit fixed object crashes, the risk reduction is taken from the estimate for hit fixed object crashes in 70/80/90 zones. Insufficient cases of hit fixed object crashes occurring in 50/60 km/h zones were identified in the in-depth crash data to estimate benefits directly.

Table 5.13
Crash reduction factors to be applied to rates of crash involvement

Speed limit	Crash severity	Type	Risk reductions by system with conversion of fatal to injury crashes in parenthesis										
			A	B	C	D	E	F	G	H	I	J	B+J
50/60	Injury	Head on	0.67	0.67	0.67	0.67	0.67	0.09	0.11	0.09	0.28	0.63	0.69
		Hit fixed object	0.48	0.63	0.48	0.48	0.76	0.66	0.77	0.57	0.81	0.66	0.80
		Intersection	0.12	0.13	0.12	0.18	0.25	0.04	0.04	0.04	0.08	0.35	0.37
		Pedestrian	0.56	0.56	0.44	0.56	0.67	0.83	0.83	0.74	0.87	0.78	0.89
		Rear End	0.71	0.72	0.64	0.71	0.71	0.58	0.69	0.39	0.80	0.47	0.73
	Fatal	Pedestrian	0.51 (-0.21)	0.51 (-0.21)	0.50 (-0.50)	0.51 (-0.21)	0.51 (-0.21)	0.84 (-0.84)	0.92 (-0.92)	0.65 (-0.65)	0.94 (-0.93)	0.76 (-0.75)	0.84 (-0.53)
		Hit fixed object*	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.34 (-0.34)	0.44 (-0.44)	0.34 (-0.34)	0.77 (-0.77)	0.49 (-0.49)	0.49 (-0.49)
70/80/90	Injury	Head on	0.32	0.47	0.32	0.32	0.45	0.54	0.63	0.52	0.64	0.59	0.70
		Hit fixed object	0.48	0.70	0.40	0.48	0.48	0.38	0.49	0.23	0.49	0.36	0.70
		Intersection	0.27	0.29	0.11	0.43	0.54	0.19	0.23	0.17	0.30	0.47	0.63
		Pedestrian	1.00	1.00	0.00	1.00	1.00	0.44	0.44	0.44	0.56	0.51	1.00
		Rear End	1.00	1.00	0.87	1.00	1.00	0.72	0.86	0.54	0.86	0.72	1.00
	Fatal	Intersection	0.48 (-0.48)	0.48 (-0.48)	0.19 (-0.19)	0.48 (-0.48)	0.48 (-0.48)	0.30 (-0.30)	0.30 (-0.30)	0.30 (-0.30)	0.32 (-0.32)	0.33 (-0.33)	0.48 (-0.48)
		Head on	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.09 (-0.09)	0.09 (-0.09)	0.09 (-0.09)	0.17 (-0.17)	0.37 (-0.37)	0.37 (-0.37)
		Hit fixed object	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.00 (-0.00)	0.34 (-0.34)	0.44 (-0.44)	0.34 (-0.34)	0.77 (-0.77)	0.49 (-0.49)	0.49 (-0.49)
100/110	Injury	Head on	-0.60	0.91	0.54	0.60	0.64	0.54	0.65	0.54	0.72	0.77	0.93
		Hit fixed object	-0.10	0.15	0.05	0.11	0.10	0.16	0.32	0.10	0.45	0.13	0.21
		Intersection	-0.21	0.35	0.21	0.21	0.21	0.13	0.15	0.11	0.17	0.16	0.35
		Rear end	-0.76	1.00	0.44	1.00	0.76	0.36	0.42	0.24	0.42	0.32	1.00
	Fatal	Head on	0.92 (-0.81)	0.94 (-0.84)	0.87 (-0.87)	0.92 (-0.81)	0.92 (-0.81)	0.46 (-0.46)	0.57 (-0.57)	0.46 (-0.46)	0.79 (-0.79)	0.79 (-0.79)	0.94 (-0.84)
		Hit fixed object	0.22 (-0.22)	0.31 (-0.11)	0.22 (-0.22)	0.22 (-0.22)	0.23 (-0.23)	0.15 (-0.15)	0.17 (-0.17)	0.11 (-0.11)	0.17 (-0.17)	0.09 (-0.09)	0.36 (-0.16)

* Risk reductions taken from fatal hit fixed object crashes in 70/80/90 zones

These changes in average risk were then weighted by the rate of crash involvement. Rates of crash involvement were estimated as described in the following sections.

5.2.2 Benefit – cost analysis

Vehicle age distribution in crashes

The distributions of the ages of crashed passenger vehicles were calculated for those crash types identified as accounting for the majority of forward collisions likely to be affected by the presence of an FCAT system. The distributions were based on the New South Wales crash data, as described in the methods section. The distribution of heavy vehicle ages was aggregated over crash type and severity.

Aggregations in the case of heavy vehicle crashes were necessary because of the relatively low number of relevant crashes.

Figure 5.23 shows the resulting (normalised) vehicle age distributions for each crash type.

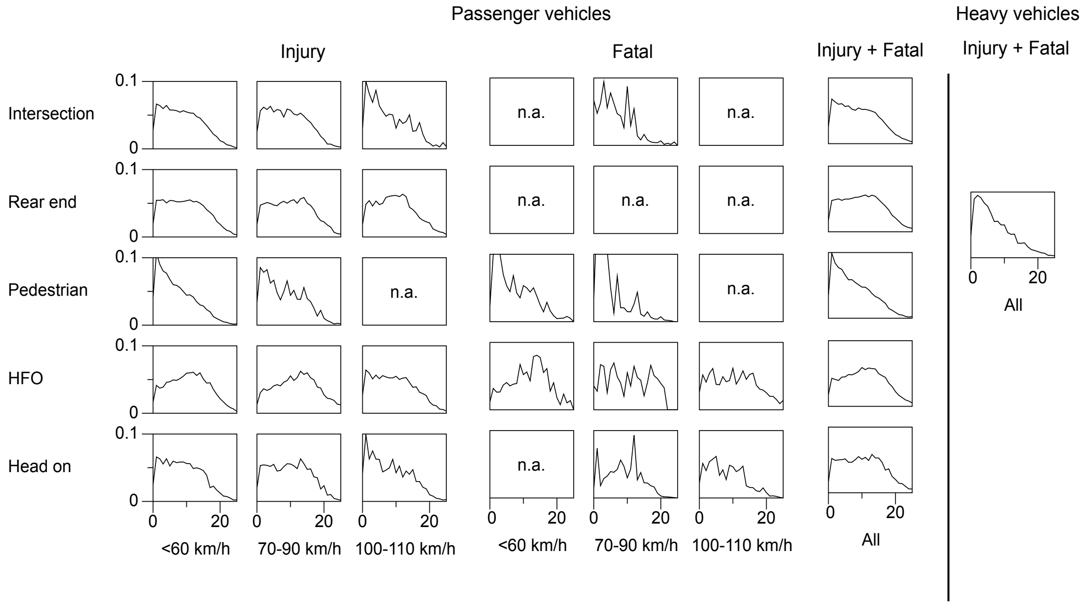

Figure 5.23
Vehicle age distributions in crashes for crash types examined in the simulation study (imputed from NSW crash data 1999-2009 and normalised)

Each distribution was discounted using a rate of three per cent per annum for the purpose of calculating discounted rates of crash involvement. This discount rate was used by BITRE when considering the costs of crashes (BITRE, 2009). It is acknowledged that this rate is lower than rates used in some other settings. For example in regulation setting in Australia, a higher rate - eight per cent - has previously been recommended (Harrison, 2010), but three per cent is consistent with best-practice guidelines when there is an absence of a risk premium in the calculation (Commonwealth of Australia, 2006). However, it should be noted that any future evaluation of regulatory proposals in relation to FCAT systems may consider a discount rate of three percent to be on the low side, and an alternative rate may be considered more appropriate for such evaluation.

For each distribution, the discounting reduces the effective crash involvement by some fraction, depending on the age of the vehicles in crashes: when the crashes tend to involve new vehicles, the discounting effect is mild, and is stronger when crashes tend to involve older vehicles. The discounting fraction arises directly from the shape of the age distribution of vehicles in crashes, as given in Figure 5.19. For the present purpose, the total crash rate (per vehicle) over the first 25 years of each cohort's age was adjusted with the discounting fraction calculated for each crash type.

Rates of crash involvement and discounted crash rates

The rates of crash involvement (per vehicle, summed over 25 years) were calculated for individual year-of-manufacture cohorts from 1999 to 2009 using the imputation methods described in the methods section. The trend in these cohorts was used to impute crash rates for vehicles built in each year from 2010 to 2020. Imputed crash rates were calculated for each crash type in each speed zone.

The overall trends in the crash rates across all relevant crash types are shown in Figure 5.24 to Figure 5.27.

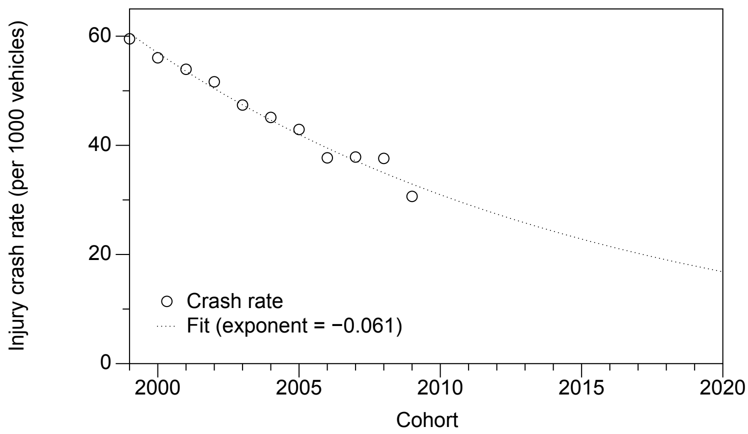

Figure 5.24
Trend in imputed injury crash rates for passenger vehicle cohorts and a projection to 2020 (Relevant forward collision crashes only)

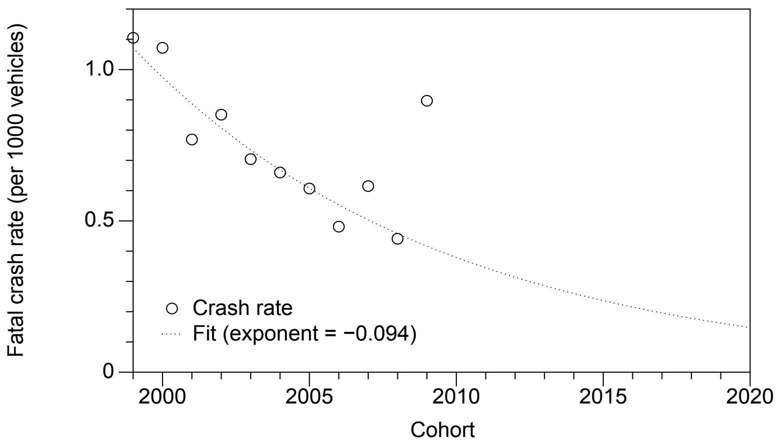

Figure 5.25
Trend in the imputed fatal crash rate for passenger vehicle cohorts and a projection to 2020 (2009 was omitted from the projection calculation given its position and that the imputed number is based on a very small number of crashes in the crash database, limiting its reliability; relevant forward collision crashes only)

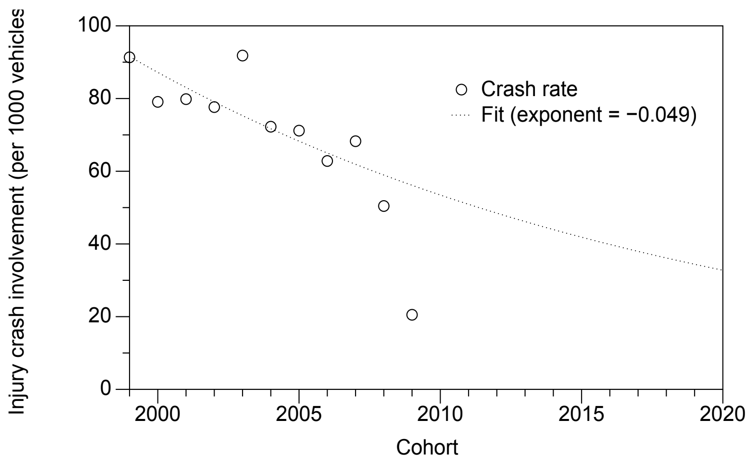

Figure 5.26
Trend in the imputed injury crash rate for heavy vehicle cohorts and a projection to 2020
(2009 was omitted from the projection calculation given its position and that the imputed number is based on a very small number of crashes in the crash database, limiting its reliability; relevant forward collision crashes only)

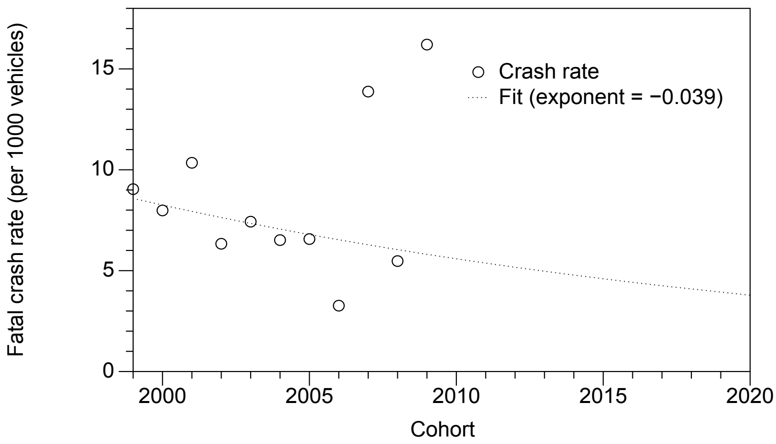

Figure 5.27
Trend in the imputed fatal crash rate for heavy vehicle cohorts and a projection to 2020
(2009 was omitted from the projection calculation given its position and that the imputed number is based on a very small number of crashes in the crash database, limiting its reliability; relevant forward collision crashes only)

It is apparent that overall crash involvement per vehicle is declining with successive cohorts of vehicles. This implies that the benefits of any crash reduction technology will differ according to the year in which it is applied to a cohort of vehicles.

Trends in the imputed crash involvement of vehicles were calculated for each crash type over the period 1999-2009 and projected to 2020. For heavy vehicles, trends in crash rates were calculated for injury and fatal crashes but aggregated over crash type. The projected rates of crash involvement per 1000 vehicles are shown in Table 5.14. Rates are given by severity, crash type and speed limit. Discounted rates are given in Appendix C.

In the case of hit-fixed-object crashes, only a fraction of the crash involvement rate is given in Table 5.14. In these cases, loss of control is often involved and it was decided that such crashes should not be counted in crashes likely to be affected by an FCAT system for several reasons:

- FCAT systems will be installed on vehicles with ESC, and as such, historical rates of hit-fixed object crashes are a poor guide to the incidence in the future.
- FCAT systems may not operate effectively at high vehicle yaw rates.
- The simulations performed did not consider such crashes.

Estimation from CASRs in-depth data suggested that about two thirds of hit-fixed-object crashes were due to loss-of-control. Hence the rates of hit-fixed-object crashes reported in Table 5.14 are one-third the rates imputed for each hit-fixed-object category.

Table 5.14
Projected undiscounted crash involvement per 1000 vehicles for vehicle cohorts from 2010 to 2020, by crash type for passenger vehicles and overall for heavy vehicles

Speed limit	Crash severity	Type	Year of manufacture cohort										
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
50/60	Injury	Intersection	7.36	6.95	6.56	6.20	5.86	5.53	5.23	4.94	4.67	4.41	4.16
		Rear end	6.47	6.06	5.69	5.33	5.00	4.69	4.40	4.12	3.87	3.63	3.40
		Pedestrian	2.67	2.50	2.33	2.18	2.04	1.91	1.78	1.67	1.56	1.46	1.36
		Head on	0.56	0.52	0.47	0.44	0.40	0.37	0.34	0.31	0.28	0.26	0.24
		Hit fixed object	1.46	1.38	1.31	1.24	1.18	1.12	1.06	1.01	0.96	0.91	0.86
	Fatal	Pedestrian	0.049	0.045	0.042	0.038	0.035	0.032	0.029	0.027	0.025	0.023	0.021
		Hit fixed object	0.054	0.052	0.051	0.049	0.048	0.046	0.045	0.044	0.042	0.041	0.040
70/80/90	Injury	Rear end	3.05	2.90	2.75	2.62	2.49	2.36	2.25	2.14	2.03	1.93	1.83
		Pedestrian	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.10	0.10
		Hit fixed object	0.81	0.77	0.74	0.71	0.68	0.65	0.62	0.59	0.57	0.54	0.52
		Intersection	1.50	1.43	1.36	1.29	1.22	1.16	1.11	1.05	1.00	0.95	0.90
		Head on	0.34	0.32	0.29	0.27	0.25	0.24	0.22	0.20	0.19	0.18	0.16
	Fatal	Intersection	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
		Head on	0.044	0.040	0.037	0.033	0.031	0.028	0.026	0.023	0.021	0.020	0.018
		Hit fixed object	0.015	0.013	0.012	0.011	0.010	0.009	0.008	0.007	0.006	0.006	0.005
100/110	Injury	Head on	0.14	0.12	0.11	0.10	0.08	0.07	0.07	0.06	0.05	0.04	0.04
		Rear end	0.64	0.62	0.59	0.57	0.54	0.52	0.50	0.48	0.46	0.44	0.43
		Hit fixed object	0.57	0.52	0.48	0.44	0.40	0.37	0.34	0.31	0.29	0.26	0.24
		Intersection	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04
	Fatal	Head on	0.070	0.064	0.059	0.054	0.050	0.045	0.042	0.038	0.035	0.032	0.029
		Hit fixed object	0.066	0.066	0.066	0.066	0.066	0.065	0.065	0.065	0.065	0.065	0.065
Heavy vehicle	Injury	All FCAT relevant	37.1	33.7	30.7	27.9	25.4	23.1	21.0	19.1	17.4	15.8	14.4
	Fatal	All FCAT relevant	8.1	8.2	8.2	8.3	8.4	8.4	8.5	8.6	8.6	8.7	8.8

These crash numbers are monetised after discounting in Table 5.15. Note that these costs refer to fatal and injury crashes only and make no allowance for property damage crashes.

Table 5.15
Willingness to pay crash costs (2012 dollars, fatal and injury crashes only) per vehicle for vehicle cohorts from 2010 to 2020, by crash type for passenger vehicles and overall for heavy vehicles

Speed limit	Degree	Type	Year of manufacture cohort										
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
50/60	Injury	Intersection	701	662	625	591	558	527	498	470	444	420	397
		Rear end	599	562	527	494	463	434	407	382	358	336	315
		Pedestrian	267	250	233	218	204	191	178	167	156	146	136
		Head on	54	49	45	41	38	35	32	29	27	25	23
		Hit fixed object	132	125	118	112	107	101	96	91	86	82	78
	Fatal	Pedestrian	250	230	211	193	177	163	149	137	126	115	106
		Hit fixed object	240	233	226	220	213	207	201	195	189	183	178
	Total		**2242**	**2110**	**1986**	**1869**	**1760**	**1657**	**1561**	**1471**	**1386**	**1306**	**1231**
70/80/90	Injury	Rear end	278	264	251	239	227	216	205	195	185	176	167
		Pedestrian	19	17	16	15	14	13	12	11	11	10	9
		Hit fixed object	70	67	65	62	59	57	54	52	50	48	45
		Intersection	141	134	128	122	116	110	104	99	94	90	85
		Head on	31	29	27	25	23	22	20	19	18	16	15
	Fatal	Intersection	154	154	154	154	154	154	154	154	154	154	154
		Head on	213	195	178	163	149	136	124	114	104	95	87
		Hit fixed object	69	62	56	50	45	41	37	33	30	27	24
	Total		**976**	**924**	**875**	**830**	**787**	**748**	**711**	**677**	**645**	**615**	**588**
100/110	Injury	Head on	13	12	10	9	8	7	6	6	5	4	4
		Rear end	59	57	55	53	50	48	46	45	43	41	39
		Hit fixed object	53	49	45	41	38	35	32	29	27	25	23
		Intersection	11	10	9	8	7	6	6	5	4	4	4
	Fatal	Head on	350	320	294	269	247	226	207	190	174	160	146
		Hit fixed object	306	305	305	304	303	303	302	302	301	301	300
	Total		**792**	**753**	**717**	**684**	**653**	**626**	**600**	**576**	**554**	**534**	**516**
Passenger	Total		**4010**	**3787**	**3578**	**3383**	**3201**	**3031**	**2872**	**2724**	**2586**	**2456**	**2335**
Heavy vehicle	Injury	All FCAT relevant	3729	3392	3085	2807	2553	2322	2113	1922	1748	1590	1447
	Fatal	All FCAT relevant	40903	41217	41534	41853	42174	42498	42824	43153	43485	43819	44155
	Total		**44632**	**44609**	**44619**	**44660**	**44727**	**44820**	**44937**	**45075**	**45233**	**45409**	**45602**

Aggregate changes in risk and benefits for each system

The following tables provide the results of overall potential crash reductions and potential monetised crash reductions. In the case of the monetised benefits, where fatal risks are converted to injury risks, the injury cost is subtracted from the value of the fatal crash reduction. However, in the tables of crash reductions, the conversion to injury risk is not subtracted from the corresponding fatal risk reduction. In the latter case, the additional injuries that might arise from the reduction in the fatal crashes are very small compared to the overall number of injury crashes.

Table 5.16 gives the monetised benefits of each system for vehicle cohorts from 2010 to 2020. The most effective system (B plus J) is predicted to have a per-vehicle benefit of $1430 in the 2020 vehicle cohort, and an average of $1938 over all cohorts. The minimum system consisting of a short range and a low time-to-collision intervention strategy is predicted to have a per-vehicle benefit of $715 in the 2020 cohort and an average of $978 over all cohorts.

The percentage crash reductions are shown in Table 5.17. Large reductions in fatal and injury crash risk are predicted by the analysis. Note though that no adjustment has been made for system unreliability here: if FCAT systems do not successfully identify collision threats in situations where they might (due to interference or poor visibility for some vision based systems) then effects will be correspondingly reduced.

Table 5.16
Per-vehicle benefit (fatal and injury crash reductions) for vehicle cohorts from 2010 to 2020, by crash type for passenger vehicles

System	Year of manufacture cohort											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Long Range												
A: Baseline	1777	1671	1572	1479	1393	1313	1238	1168	1102	1041	984	1340
B: Higher braking force	1895	1784	1679	1582	1492	1407	1329	1255	1186	1122	1062	1436
C: Shorter TTC	1540	1445	1356	1274	1197	1126	1059	997	939	885	835	1150
D: Longer TTC	1860	1749	1646	1550	1460	1376	1298	1225	1156	1093	1033	1404
E: Wider angle	1982	1864	1755	1652	1557	1467	1384	1306	1233	1165	1102	1497
Short Range												
F: Baseline	1582	1486	1397	1314	1237	1164	1097	1034	975	920	869	1189
G: Higher braking force	1829	1718	1615	1519	1429	1345	1267	1194	1126	1063	1003	1374
H: Shorter TTC	1302	1223	1149	1081	1017	957	902	850	802	757	715	978
I: Wider detection area	2170	2038	1915	1800	1693	1593	1500	1413	1332	1257	1186	1627
J: Wide angle	1972	1849	1736	1630	1531	1439	1353	1273	1199	1129	1064	1470
Combination												
B plus J	2562	2411	2269	2137	2014	1900	1793	1693	1599	1512	1430	1938

Table 5.17
Percentage reductions in crashes (average of all cohorts)

System	Reduction			
	Fatal		Injury	
	Of all relevant forward collision	Of all fatal crashes	Of all relevant forward collision	Of all injury crashes
Long Range				
A: Baseline	34	23	50	36
B: Higher braking force	37	25	53	38
C: Shorter TTC	30	21	42	30
D: Longer TTC	34	23	53	38
E: Wider angle	34	24	58	42
Short Range				
F: Baseline	34	24	41	30
G: Higher braking force	40	28	48	34
H: Shorter TTC	31	21	32	23
I: Wider detection area	52	36	53	38
J: Wide angle	44	31	50	36
Combination				
B plus J	56	39	67	48

It should be noted that in all cases, no allowance has been made for false-negative system responses or system unreliability.

Benefit - cost ratios

Recent costs for original equipment FCAT systems in Australia and Europe vary from $1500 to $3,350, as discussed in Section 4.3. However, the most expensive system is similar to the combination system (B+J) rather than being representative of all the systems. Therefore the range of prices applied to the benefits of single systems (A to J) was $1500 to $2500 and the cost of $3350 was only applied to the combination system. Of the single systems, the short range system with the shorter TTC was the system that produced the least benefit and the short range system with the wider detection area produced the greatest benefit, slightly higher than the long range systems with the higher braking force (See Table 5.7). To calculate the range of benefit-cost ratios, the per-vehicle benefit shown in Table 5.7 was multiplied by these costs. For vehicles produced this year (2012), the benefit cost ratio was found to be 0.5 to 1.3 for the single systems, reducing to 0.4 to 1.1 by the middle of the decade and to 0.3 to 0.8 by the end of the decade. These benefit cost ratios use the current prices of FCAT systems, which may reduce considerably in future years. The benefit cost ratio of the combination system is 0.7 this year, reducing to 0.6 in 2015 and 0.4 in 2020. Benefit cost ratios are summarised in Table 5.18. For the single systems A through J a range is given that considers the current range of prices for such systems. The combination system BCR only uses one price and therefore does not have a range.

No allowance has been made in these figures for false negative responses elicited by FCAT systems, nor for other forms of reliability problems. The BCRs might be reduced by some percentage depending on this rate of unreliability.

Table 5.18
Benefit-cost ratios for light passenger vehicle FCAT systems by vehicle cohort

System	Year of manufacture cohort									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Long Range										
A: Baseline	0.6 - 1.0	0.6 - 1.0	0.6 - 0.9	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.4 - 0.7	0.5 - 0.9
B: Higher braking force	0.7 - 1.1	0.6 - 1.1	0.6 - 1.0	0.6 - 0.9	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.6 - 1.0
C: Shorter TTC	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.4 - 0.6	0.4 - 0.6	0.3 - 0.6	0.5 - 0.8
D: Longer TTC	0.7 - 1.1	0.6 - 1.0	0.6 - 1.0	0.6 - 0.9	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.6 - 0.9
E: Wider angle	0.7 - 1.2	0.7 - 1.1	0.6 - 1.0	0.6 - 1.0	0.6 - 0.9	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.6 - 1.0
Short Range										
F: Baseline	0.6 - 0.9	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.4 - 0.7	0.4 - 0.6	0.3 - 0.6	0.5 - 0.8
G: Higher braking force	0.6 - 1.1	0.6 - 1.0	0.6 - 1.0	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.5 - 0.9
H: Shorter TTC	0.5 - 0.8	0.4 - 0.7	0.4 - 0.7	0.4 - 0.6	0.4 - 0.6	0.3 - 0.6	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.4 - 0.7
I: Wider detection area	0.8 - 1.3	0.7 - 1.2	0.7 - 1.1	0.6 - 1.1	0.6 - 1.0	0.6 - 0.9	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.7 - 1.1
J: Wide angle	0.7 - 1.2	0.7 - 1.1	0.6 - 1.0	0.6 - 1.0	0.5 - 0.9	0.5 - 0.8	0.5 - 0.8	0.5 - 0.8	0.4 - 0.7	0.6 - 1.0
Combination										
B plus J	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.6

Heavy vehicles

Table 5.15 provides crash costs associated with fatal and injury crashes that might benefit from FCAT systems. It was not possible to estimate benefits in heavy vehicles using the same methodology employed for passenger vehicles. Crash numbers are much lower for heavy vehicles, even though the rate of crash involvement is relatively high. This meant that it was not possible to impute crash involvement by crash type. Furthermore, too few in-depth cases involving heavy vehicles were available for detailed simulation. Crash risks associated with given delta-v values estimated from passenger vehicle crashes may not apply to heavy vehicle crashes, particularly in truck-car crashes where structural incompatibilities would add to injury risks.

Given these limitations, an estimate of benefit can nevertheless be made assuming that overall reductions in crash risk are similar to those that have been estimated for passenger vehicles in this report. If it assumed that the heavy vehicle system would not intervene aggressively, then benefit estimates from a system such as C might apply. Using the benefit estimates given in Table 5.17 for 2012 and the costs of heavy vehicle crashes given in Table 5.15 indicates that the benefit will be close to $13,700 per vehicle.

The cost of heavy vehicle systems ranges from $1400 to $5000 (see Section 4.3). At these prices the benefit cost ratios are easily above unity, ranging from 2.7 to 9.8.

6 Discussion and conclusions

Main points

- The simulation study detailed in this report predicts significant crash reductions with the introduction of FCAT systems.
- Between 20 and 40 per cent of all fatal crashes and between 30 and 50 per cent of all injury crashes might be prevented with FCAT systems (note that these figures do not account for any unreliability in operation).
- The estimates are consistent with previous studies that have suggested reductions of up to and in excess of 40 per cent.
- The greatest estimated benefit is from a system that combines long and short range sensing.
- Systems with expansive fields of view and that are highly reactive have a greater theoretical effect, but may suffer from the problem of false-positive responses.
- A narrow field of view that reduces the chance of false-positive interventions appears to provide substantial benefit; the results of such a system were comparable to a system with a wide field of view.
- Estimated benefit-cost ratios for passenger vehicles are marginal at less than one in most instances, due to high system costs and a declining per-vehicle crash rate. However, a halving of system costs would see BCRs exceed one.
- Heavy vehicle BCRs are much higher: between 2.7 and 9.8.

Recommendations

- Encourage the uptake of FCAT systems by heavy vehicle operators and in passenger vehicle markets as soon as possible.
- Liaise with industry groups such as the Federal Chamber of Automotive Industries and the Truck Industry Council with a view to finding pathways for the wider-scale introduction of FCAT technologies.
- In programs such as ANCAP, provide substantial credit for the installation of effective FCAT systems.
- Encourage the creation of performance standards for such systems, to ensure uniformly high effectiveness, and to provide a means of assessment by ANCAP.
- Monitor and evaluate of system as they are introduced, to confirm or otherwise the benefits of the systems that have been estimated via simulation in this study and similar studies.

6.1 Overview

This report has estimated the likely effect of FCAT systems on the risks of injury and fatal crash involvement. Changes in risk were based on an analysis of 104 relevant crashes that had been investigated at the scene and reconstructed.

The methodology employed was as follows:

- The effects of various styles of FCAT systems were simulated in order to estimate the reduction in collision speed that might have been observed if the forward-collision vehicle in the crash been equipped with each style of FCAT system.
- The change in risk that corresponds to the reduction in collision speed was estimated from published injury risk curves.
- The average change in risk was computed for specific crash types and speed zone combinations.
- These changes in risk were then weighted by the expected incidence of crashes in future cohorts of vehicles.
- The main results were estimates of the aggregate change in crash rates that various styles of FCAT systems might produce, the monetised benefit of the reductions and the benefit cost ratios.

Additionally, trials of FCAT systems were described. Several field trials of FCAT systems have been conducted in the past, but the results have been inconclusive in respect of whether FCAT systems were effective in reducing crash rates. The number of vehicles equipped with FCAT systems in these field trials has generally been small and as such it would be unlikely that a reduction in crash risk would have become apparent. Nevertheless, field trials have suggested that forward collision warning systems are generally accepted by drivers using the systems, and do not appear to have negative effects on their driving behaviour. There have been some estimates of benefits made through analysis of crash records, but there are only a limited number of these. Most estimates of the benefits of FCAT systems have been made through simulations similar to the study described in this report. However, all published estimates are impressive: reductions of up to and in excess of 40 per cent of crashes are predicted at all levels of crash severity.

The present study has predicted similarly large reductions in the incidence of injury and fatal crashes. The reductions that have been estimated were dependent on the style of FCAT system modelled: longer range and longer time to collision algorithms with expanded fields of view produce the highest estimated reductions, but technical challenges exist for such systems: if the range of such systems is too expansive, then eliminating false-positive responses is likely to be a challenge.

More conservative systems that monitor a short range directly ahead of the vehicle are also likely to have a substantial effect. System “G” which monitors a narrow field in front of the vehicle, but intervenes with full braking after a short reaction time was predicted to provide substantial benefit, and was predicted to prevent almost as many fatalities as the more comprehensive system that includes long-range and short-range sensors (B + J).

Despite high effectiveness, benefit-cost ratios make for only a marginally positive economic case. This is partly due to declining crash rates in Australia and partly due to high system costs. BCR calculations will depend on the true marginal costs of production and implementation of systems in the future. Historical precedent would suggest that costs at the point of supply will decline for such systems in the future.

6.2 Limitations and assumptions

There are several identified limitations in the methodology and these are described below.

Limitations and confidence in the overall results

The results that have been presented in this report have varying levels of confidence attached to them. The results that are probably the most reliable are the projected crash rates of future cohorts of vehicles; care was taken to ensure that the estimates of the number and timing of crashes occurring within future cohorts of vehicles were sound. However, if present trends in crash numbers change, these projections will diverge from actual crash rates.

With respect to the risk reductions based on the simulation results, confidence is lower, not because of the simulation results themselves, but because 104 crashes were used to represent all relevant crashes. Hence, confidence is highest when speed changes in individual crashes are considered. When converted to change in average risk over all crashes, confidence is highest when the results are aggregated after weighting to reflect the incidence of each crash type in the mass data (thus minimising random effects in estimated risk reductions in individual crash types). We would recommend caution with the use of changes in risk that have been estimated for any one crash type and speed zone in this study, as relatively few crashes may be used to generate the average change in risk in each category. Better individual risk reductions would be obtained with further simulations of more crashes.

Results such as the monetised benefit of systems and their benefit-cost ratios are the result of combining crash rates, changes in risk, costs of FCAT systems, and costs of crashes. Hence, confidence in such results should be expected to be less than the confidence in the components used to calculate them.

The following is a list of results that have been generated in this study, ranked in an approximate order of confidence:

- Projected aggregate per-vehicle crash rates
- Projected per-vehicle crash rates for each crash type
- Projected average present value of FCAT-relevant crashes
- Changes in speed brought about by FCAT systems in individual crash scenarios
- Aggregate change in crash risk brought about by each FCAT system
- Projected aggregate benefit of FCAT systems and benefit cost ratios
- Projected change in crash risk in individual crash types
- Projected benefit of FCAT systems in each crash type

Risk and cost estimates

The risk curve that was used in the analysis of occupant injury was based on US crash data from 1995-1999. Given that crashworthiness of vehicles has been found to increase with model year (Anderson, Doecke and Searson, 2009; Newstead, Watson and Cameron, 2011), it is probable that the chance of injury or fatality, at a given speed, is less in current and future cohorts of vehicles than the risk curves would suggest. As relative changes in risk are used in this study, errors in absolute risk levels are likely to be attenuated when estimating relative changes in risk.

The risk curves were defined as a function of delta-v rather than the closing speed that was produced by the simulations. The relationship between closing speed and delta-v in each relevant crash type was estimated from data within CASR's in-depth crash database.

The risk curves represent an average risk over all impact configurations, whereas the risk of injury is likely to differ between crash configurations. For example, injury risk is likely to be higher in a side impact than in a rear or even frontal impact. All the FCAT vehicles in the analysis had frontal crashes; however the struck vehicle, whose occupants' injury levels were also considered, experienced a variety of impact directions.

Average willingness-to-pay estimates of crash costs were used to estimate benefits of reduced crashes. Costs may not be the same for all crash types and speed zones – it is reasonable to assume that injury costs in 50 km/h and 60 km/h speed zones might be less than in higher speed zones. As crash reductions due to FCAT systems were not estimated to be uniformly distributed over all crash types and speed zones, there is likely to be some error in using average costs of injury for all crash types.

Simulations

When conducting the simulations it was assumed that only one vehicle was equipped with an FCAT system. This was consistent with the economic analysis where vehicle cohorts up to 2020 were considered. Given the age of vehicles in crashes, the probability will be low that a crash partner will have an FCAT system as well, particularly in early years where the majority of the economic benefit will be realised. Furthermore, it was apparent that in most crash configurations, the presence of an FCAT system on the struck vehicle would have had little or no effect on the collision speed. The one crash configuration in particular where an effect might be expected is head on crashes where one vehicle drifts into the path of an oncoming vehicle without losing control. In this scenario the effect of a given FCAT system may be doubled. If FCAT fleet penetration becomes sufficiently high in future years that two vehicles crashing are likely to both have and FCAT systems, a benefit beyond what has been accounted for in this study could be realised.

The simulation methodology did not account for crashes that may have been avoided due to one vehicle slowing sufficiently to allow the other vehicle to pass without a collision occurring. This is most likely to affect right angle crashes (DCA 101). This limitation of the model contributes an underestimate of the effectiveness of FCAT. Conversely, it is possible that rear end crashes may occur due to a vehicle following the FCAT vehicle not braking as quickly or hard as the FCAT vehicle. Schittenhelm (2009), however, found that the opposite was true. He suggested that the system caused earlier, less severe braking interventions and helped to avoid the last moment panic braking that can precede a vehicle being struck in the rear.

Crash incidence

In the case of hit-fixed-object crashes, only those crashes where the vehicle did not lose control were presumed to be relevant to FCAT. The proportion of hit fixed object crashes that do not involve a loss of control is not identifiable in the mass crash data. It was assumed that one third of hit-fixed-object crashes do not involve loss of control; this proportion is based on CASR in-depth study data, and it should be noted that the proportion was only derived from speed zones of 80 km/h and above. For the purpose of this analysis this proportion was applied to all speed zones. It seems likely that a greater proportion of hit fixed object crashes may be non-loss of control crashes in low speed zones as they tend not to contain features, such as unsealed shoulders and curves, that are typical contributing factors in loss of control crashes. If this is the case the analysis has underestimated the effect of FCAT on hit fixed object crashes in 50 and 60 km/h speed zones.

Costs and benefits of systems

The marginal cost of vehicle technologies can reduce considerably with time particularly when the technology is mature and widespread. When vehicle technologies are new, they may only be offered as options on luxury vehicles and the consumer may pay a premium. Historically, the marginal cost of technologies appears to be absorbed in the new cost of vehicles (Anderson *et al.*, 2011) and the real costs of vehicles has not appreciably changed over the last 20 years or so. These kind of factors produce uncertainty in the calculation of BCRs, when the relevant system costs are those of a maturing technology (it is highly unlikely that FCAT would become more expensive). Therefore more emphasis should be placed on the results of per-vehicle benefits by vehicle year (Table 5.16). These break-even costs can be used to determine cost effectiveness for technologies in future cohorts of vehicles.

The heavy vehicle analysis conducted was coarse in comparison to the light vehicle analysis: general effectiveness estimates, based on the light passenger vehicle analysis, were applied to rates of heavy vehicle crash involvement. However, because the per-vehicle crash costs are so high for heavy vehicles, the cost-effectiveness of FCAT systems for heavy vehicles could be much lower (one-third to one-quarter the effectiveness assumed) before system costs exceed the benefits. FCAT systems for heavy vehicles have BCRs up to nine times greater than the BCRs for passenger vehicles.

6.3 Conclusions and recommendations

Forward collision avoidance technologies that sense other road users and intervene when a collision is imminent are likely to produce large reductions in the number of crashes. Even allowing for a moderate level of unreliability, up to 30 per cent of all fatal crashes and up to 40 per cent of all injury crashes could be prevented in vehicles that are equipped with such systems. This prediction is based on a series of 104 crashes that are documented in CASR's in-depth crash investigation program, and an analysis of the typical pattern of crash involvement over the life of vehicles in Australia.

Reduced crash speeds, and hence energy, potentiate the benefits of vehicle secondary safety systems and produce nonlinear reductions in injury risk. Hence it is not surprising that effective crash speed reduction technologies should produce large reductions in fatal and injury crash risk. Accordingly, such systems need to be promoted.

Several styles of FCAT systems (differing in range, detection zone, responsiveness etc.) were simulated. The greatest benefit was predicted to result from systems that combine a long-range detection system (based on an adaptive cruise control system, for example), with a short range, wide angle system (as might be designed for city speeds and pedestrian detection). However, even short range, narrowly focused but highly responsive systems were predicted to give large benefits. The style of system also determines the complexity of the logic required to asses whether objects, pedestrians and vehicles in the detection zone constitute a threat of collision; too many false positive signals and the driver will deactivate the system, so there is some merit in reducing the detection zone. The methods described in this report allow the trade-offs between the size of the detection zone, the responsiveness and the effectiveness of systems to be studied.

A potential obstacle to the wide-scale introduction of such systems in the system cost, which appears to be high, particularly relative to the per-vehicle benefit of such systems. No such obstacle exists for heavy vehicles; given their relatively high rates of crash involvement, benefit-cost ratios are high.

Given that some systems might have multiple uses (adaptive cruise control, automated sign detection for vision systems etc.) benefits to the driver might go beyond crash avoidance. Therefore, a refinement of BCRs for passenger vehicles might include understanding the true marginal costs of crash avoidance functions built into such systems, noting that the break-even costs appear to be in the range of $800 - $2000.

Encouragement should be given to passenger vehicle manufacturers to install such systems in order to reduce the marginal costs as even relatively simple short-range systems that intervene strongly may provide substantial benefits.

Recommendations

- Encourage the uptake of FCAT systems by heavy vehicle operators and in passenger vehicle markets as soon as possible.
- Liaise with industry groups such as the Federal Chamber of Automotive Industries and the Truck Industry Council with a view to finding pathways for the wider-scale introduction of FCAT technologies.
- In programs such as ANCAP, provide substantial credit for the installation of effective FCAT systems.
- Encourage the creation of performance standards for such systems, to ensure uniformly high effectiveness, and to provide a means of assessment by ANCAP.
- Monitor and evaluate systems as they are introduced, to confirm or otherwise the benefits of the systems that have been estimated via simulation in this study and similar studies.

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Appendix A – Performance tests for FCAT

This section reviews various international projects that are developing performance tests for FCAT systems - particularly Autonomous Emergency Braking (AEB). Other systems such as driver warning systems tend to be a subset of AEB for performance testing purposes.

Research Council for Automobile Repairs (RCAR)

RCAR members are research centres supported by or with close connections with insurers. Current membership includes 24 centres in 19 countries and five continents. IAG Research, based in Sydney, is a member of RCAR.

Several RCAR members have formed a focus group, the AEB Group, with the aim of defining a set of test procedures that can be used by consumer test organisations such as Euro NCAP, IIHS and Thatcham. The group is supported by a vehicle manufacturer, to aid in understanding vehicle design issues, and a tier 1 component supplier, to aid in identifying technological constraints. The group is also supported by recognised accidentology experts.

The AEB group is basing its test procedures on real crash scenarios taking into account both frequency and severity. A range of data sources that includes insurance and national statistics as well as in-depth accident investigation have been consulted to identify scenarios of greatest importance. Specifically, the in-depth reconstructed accidents are used to identify typical pre-accident conditions. Test devices and tests able to represent these real world scenarios have been developed. These tests will be published by the Group and shared with other working parties looking at collision avoidance technologies.

A researcher from Thatcham provided this advice on the project:

> Assessing a handful of vehicles repeatedly during development of the tests last year we yielded lots of performance data and it is obvious to see there is different performance evident depending on the sensor technology employed, the level of algorithm development and sensitivity and the intervention philosophy of the vehicle manufacturer. Some systems work at low speeds only, some warn and others don't, moderate early braking and harder later braking etc. We test systems with a black box approach (i.e. present them with the target and measure the response) so we record warnings and the deceleration, speed reduction and avoidance or mitigation. Therefore estimating response times is difficult. However a large amount of information concerning senor ranges and angles of detection etc. is available online from Thatcham reports.

In 2011 Alix Weekes from Thatcham gave a presentation on the AEB Group test procedures and the potential road trauma savings from these systems (Weeks, 2011). The tests used are:

- Car-to-car rear CCR1: approaching a stopped vehicle at test speeds from 10 to 60 km/h. Speed is increased in 10km/h increments until a collision occurs or 60km/h is reached.
- Car-to-car rear CCR2: rounding a curve at 10 km/h and encountering a stationary vehicle (currently under development).
- Car-to-car rear CCR3: approaching a target vehicle moving at 20km/h. Starting at 60km/h and increasing in 10 km/h increments until a collision occurs or 80 km/h is reached (Figure A.1).

- Car-to-car rear CCR4: approaching a decelerating target vehicle. Both vehicles are initially moving at 50 km/h. With a headway (spacing) of 13 m the target vehicle decelerates at two m/s^2. This is repeated with a target vehicle deceleration of six m/s^2. It is then repeated with 40 m initial headway.
- Car-to-pedestrian CP1: unobscured pedestrian walks out from nearside. Vehicle test speed starts at 10 km/h and increased in 10 km/h increments until a collision occurs or 60 km/h is reached (Figure A.2).
- Car-to-pedestrian CP2: obscured pedestrian walks out from nearside. Vehicle test speed starts at 10 km/h and is increased in 10 km/h increments until a collision occurs or 60 km/h is reached.
- Car-to-pedestrian CP3: unobscured pedestrian runs out from farside. Vehicle test speed starts at 40 km/h and increased in 10 km/h increments until a collision occurs or 60 km/h is reached.
- Car-to-pedestrian CP4: pedestrian walking along the road at night. Vehicle test speeds of 50 km/h and 70 km/h (currently under development).
- Car-to-pedestrian CP5: car turns at junction and pedestrian walks out. Vehicle test speeds of 15 km/h and 25 km/h (currently under development).

Figure A.1
RCAR Car-to-car test

Figure A.2
RCAR Car-to-pedestrain test

Euro NCAP

Euro NCAP organises crash tests and provides motoring consumers with a realistic and independent assessment of the safety performance of some of the most popular cars sold in Europe. Established in 1997, Euro NCAP is composed of seven European Governments as well as motoring and consumer organisations in every European country.

The Euro NCAP "Advanced" system is designed to encourage the development and uptake of advanced technologies. This includes AEB. Euro NCAP currently recognises seven AEB systems, from Ford, Daimler, Volkswagen, Honda and Volvo.

To date these assessments have been conducted somewhat informally in consultation with manufacturers. However the P-NCAP group of Euro NCAP is developing an assessment protocol for this purpose, in combination with the AEB Group.

TRL Limited

TRL is a UK based transport research organisation and has conducted research on "Automated Braking Systems" for the European Commission (Grover *et al.*, 2008)

The project included a review of production systems, an analysis of braking system requirements, a review of sensing system technology and the development of performance and functional requirements.

Car and truck systems were evaluated. Comments are made about risks associated with behavioural adaptation by drivers.

Transport Canada

Transport Canada is a government organisation. It has an Ergonomics and Crash Avoidance section that is looking at AEB systems.

A researcher from Transport Canada provided this advice:

> “Transport Canada gave a presentation to the P-Safe committee of the RCAR in Vancouver in June 2010. The presentation contained pictures of our test device ("target"), the test manoeuvres we used, and results we obtained on one system in detecting a stopped/parked vehicle and in detecting a moving vehicle (vehicle moving at a constant 30 km/h). The results are somewhat old now; the vehicle's forward crash mitigation system has been upgraded and its performance improved since...
>
> We have also performed very limited testing with the Volvo XC60 with City Safety; at this stage no results are available from these tests. We are currently planning to test the Collision Mitigation system on a 2011 Acura MDX and the Low Speed Safety System on a European version of the 2012 Ford Focus Titanium.”

The tests conducted by Transport Canada were based on ISO Draft 22839 (see below) and are illustrated in the Figure A.3.

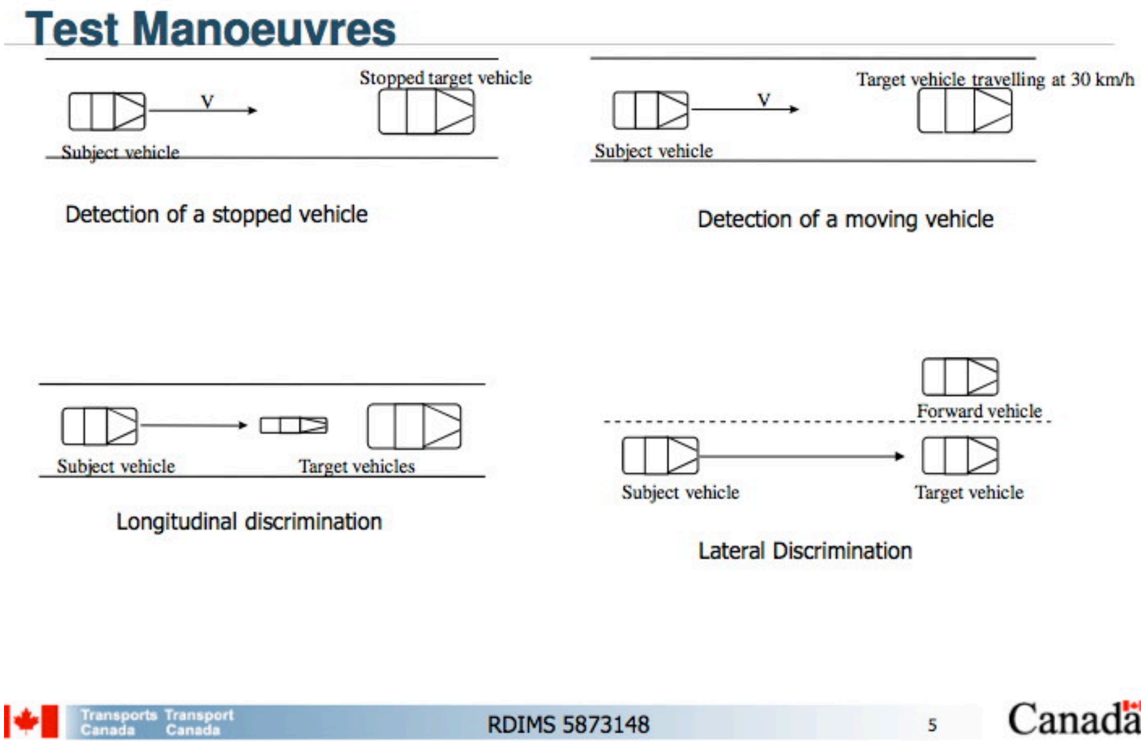

Figure A.3
Transport Canada test manoeuvres

Subject vehicle test speeds were 20, 30 and 40 km/h for the test with a stationary target vehicle. Subject vehicle test speeds were 60, 70 and 80 km/h with the target vehicle moving at 30 km/h.

The subject vehicle was tested at 60, 80 and 100 km/h for the discrimination tests, where the test simulated a motorcycle following a car or two cars in adjacent lanes.

National Highway Traffic Safety Administration (NHTSA)

NHTSA is a USA government agency and has been doing work in the field of "Crash Imminent Braking" (CIB), essentially the same as AEB.

A large number of reports are available on this research. In September 2011 NHTSA released "Objective Tests for Automatic Crash Imminent Braking Systems" (Carpenter *et al.* 2011). The manufacturers Continental, Delphi Corporation, Ford Motor Company, General Motors, and Mercedes-Benz contributed to the research. The research was conducted over several phases:

> “The first phase of the project involved target crash scenario selection and development of preliminary functional requirements...
>
> The second phase of the project involved specifying and building the test systems to be used throughout the remainder of the project. As part of this work, a survey document was distributed to key, automotive, forward-looking sensor suppliers requesting assessment of the potential performance capabilities of their technologies relative to the priority crash modes identified in the first phase...
>
> The third phase of the project involved the development, demonstration, and validation of the objective tests for evaluating CIB systems...

> The fourth and final phase of the project involved finalising the CIB performance specifications and development of the benefits estimation methodology.
>
> The recommended criteria involve a series of 10 performance tests with the subject vehicle having to detect and react to a target vehicle. The proposed pass criteria are activation in at least eight out of the 10 tests and a speed reduction of at least 6km/h."

It is understood that NHTSA is considering issuing a Notice of Rulemaking for the regulation on CIB and/or forward collision warning systems.

In 2008 US NCAP published performance requirements for Forward Collision Warning (FCW) systems. The FCW must meet each of three crash alert test requirements for the vehicle model to be listed on the US NCAP website as having this feature. The three tests involve the subject vehicle following a lead vehicle on a straight road at 72km/h. The tests are conducted under clear daytime conditions. In the first test the lead vehicle is stopped and the warning must occur no closer than 2.1 seconds to collision (time-to-collision TTC = 2.1s). In the second test the lead vehicle decelerates at 0.3 g and the warning must occur no closer than TTC 2.4s. In the third test the lead vehicle is travelling at a constant 32 km/h and the warning signal must occur no closer than TTC 2s.

Raphel and others (2011) report on an evaluation of the Mobileye camera-based forward collision warning system against the US NCAP requirements. The system met these requirements although it was recommended that other more demanding tests be performed, such as night time and curved roads. The authors note that a camera could also serve other purposes such as adaptive cruise control, high-beam control and traffic sign recognition.

Society of Automotive Engineers (SAE) USA

The SAE co-ordinates research and publish recommended practices for use within the automotive industry. The SAE has contributed to the NHTSA initiatives described above.

In 1997 the SAE published a report (Wilson *et al.*, 1997) that set out recommended performance guidelines for forward collision warning systems. The guidelines covered warning systems only and excluded autonomous emergency braking. The guidelines include the following (Wilson *et al.*, 1997):

- Must detect and alert the driver for all kinematics and dynamics of the subject and target vehicles, including stopped vehicles
- Must detect all types of licensable vehicles - including motorcycles (but not necessarily at full range)
- Must have a forward range of at least 130m
- Must have a horizontal sensor field of at least +/-8 degrees
- Must have a vertical sensor field of +/-2.5 degrees

The human-machine interface and the recommended warning signals are also discussed and a haptic signal (e.g. vibration) is recommended for an inattentive driver warning.

International Standards Organisation (ISO)

ISO TC 204/WG 14 (working group) have been working on various requirements for Forward Vehicle Collision Mitigation Systems (FVCMS). The latest version of the draft ISO 22839 on the "Operation, Performance, and Verification Requirements" of FVCMS systems was issued in January 2012. It is understood that ISO TC 204/WG 14 will be meeting in Melbourne in April 2012.

The *draft* standard covers three classes of FVCMS depending on the radius of curvature of the road (>=500m, >=250m and >=125m).

Three types of countermeasure are recognised in the draft of ISO 22839:

> "**Collision Warning (CW) Countermeasure.** Collision warning is a warning based on some combination of audible, visual and tactile or haptic sensory modes.
>
> **Speed Reduction Braking (SRB) Countermeasure.** Speed reduction braking is an automatic braking function, intended to reduce subject vehicle velocity. SRB affords the driver an improved opportunity to apply manual emergency braking, to make an emergency lane change, or to determine that no hazard is present and to disengage SRB.
>
> **Mitigation Braking (MB) Countermeasure.** Mitigation braking is automatic braking applied when a collision appears unavoidable. The peak acceleration and the jerk are limited by the design and condition of vehicle systems, and by available traction. To assist the occupants to prepare for this braking event, MB actuation will be preceded by a collision warning countermeasure, and optionally by the activation of SRB."

Light vehicles equipped with FVCMS shall be capable of fulfilling the following functions (ISO 22839):

- Detect the presence of forward vehicles.
- Determine the range and closing velocity between the subject vehicle and the detected forward vehicles.
- Determine the subject vehicle velocity.
- Determine the target vehicle centreline, or apparent centreline if part of the target vehicle is occluded from subject vehicle sensors, if the lateral offset is less than 20 per cent.
- Provide driver warnings in accordance with the FVCWS requirements.
- Activate and modulate the brakes whether or not the driver is already braking.
- Control the brake light.
- Enhance driver control based on brakes with a yaw stability capability, e.g. an ABS, ESC, VDC, or RSC system.
- Generate at least the minimum required FVCMS deceleration during an MB event for type 2 and 3 systems.
- Have the capability to provide the SRB braking profile for type 3 systems.
- After MB or SRB has been initiated, permit the driver to increase the deceleration to any higher value up to the maximum possible vehicle deceleration.

Heavy vehicles equipped with FVCMS have the same requirements but must also prevent jack-knifing:

> "FVCMS shall provide countermeasure actions when needed based on detected licensable motor vehicles intended for use on public roads, i.e. motorcycles, cars, light trucks, buses,

motor coaches, and other heavy vehicles. FVCMS may optionally detect smaller targets, such as pedestrians and human-powered cycles."

All FVCMS must have a minimum activation speed of 30 km/h or less and a maximum activation speed of at least 100 km/h.

Minimum detection areas (width, height and angles) are also specified.

Functional ability tests cover a range of scenarios. For example, the subject vehicle is travelling at 70 km/h and encounters a target vehicle, such as a motorcycle, travelling at 30 km/h. A second target vehicle is added for a "discrimination test" to ensure that a motorcycle is detected when it is following a slow moving car. See the Transport Canada item above for more details.

UNECE Working Party 29 (WP29)

UNECE WP29 has formed an informal group on Automatic Emergency Braking and Lane Departure Warning Systems (AEBS/LDW) for heavy commercial vehicles (UNECE, 2011):

> "The intention of this regulation is to establish uniform provisions for advanced emergency braking systems (AEBS) fitted to motor vehicles of the categories M2, M3, N2 and N3 primarily used under highway conditions...The system shall automatically detect a potential forward collision, provide the driver with a warning and activate the vehicle braking system to decelerate the vehicle with the purpose of avoiding or mitigating the severity of a collision in the event that the driver does not respond to the warning.
>
> A collision warning when the AEBS has detected the possibility of a collision with a preceding vehicle of category M, N or O (i.e. not category L motorcycles) in the same lane which is travelling at a slower speed, has slowed to a halt or is stationary having not being identified as moving.
>
> The functional part of the test [with a stationary target] shall start when the subject vehicle is travelling at a speed of 80 ± 2 km/h and is at a distance of at least 120 m from the target.
>
> At least one haptic or acoustic warning mode shall be provided no later than the value specified in Table I Column B of Annex 3, before the start of the emergency braking phase.
>
> At least two warning modes shall be provided no later than the value specified in Table I Column C of Annex 3, before the start of the emergency braking phase.
>
> The emergency braking phase shall not start before a time-to-collision (TTC) equal to or less than 3.0 seconds.
>
> The test is repeated with a target moving forward at 32km/h."

European Commission ASSESS

ASSESS stands for Assessment of Integrated Vehicle Safety Systems for improved vehicle safety.

The overall purpose of the ASSESS project is to develop a relevant and standardised set of test and assessment methods and associated tools for integrated vehicle safety systems with the focus on currently "on the market" pre-crash sensing systems.

Assessment methods are still being developed and are not publicly available at this time.

AsPeCSS

Assessment methodologies for forward looking Integrated Pedestrian and further extension to Cyclists Safety Systems (AsPeCSS) is a European consortium that is looking at ways to reduce serious injuries to vulnerable road users (AsPeCSS, 2012). The stated goal of AsPeCSS is:

> "To develop harmonised test and assessment procedures for forward looking integrated pedestrian safety systems that can be used for consumer rating and regulatory purposes. As such the project is meant to stimulate wide spread introduction of these systems that have high potential to improve safety of pedestrians and, in case adequate detection technology becomes available, also for pedal cyclists."

The project has links with the Euro NCAP P-NCAP initiative and with the UNECE AEB-Group and EC ASSESS projects.

ADAC

The German automobile club ADAC conducts performance tests of "advanced emergency braking systems" fitted to some production vehicles (ADAC, 2011). The vehicles tested were Audi A7, BMW 5-series, Infiniti M, Mercedes CLS, Volvo V60 and VW Passat. The test criteria were: collision warning, autonomous brake assist, autonomous brake strategy and false alarm.

The tests conducted were:

- Approaching a slow-moving object
- Approaching a decelerating object
- Approaching an object that has decelerated to a halt
- Approaching a stationary object (Figure A.4)
- Activation of autonomous brake assist (increases brake effort if driver has not pressed hard enough to avoid collision)
- Alert sequence and distance warning
- False alarm tests include vehicles in adjacent lane while on a curve, overtaking and vehicles slowing down to make a sharp turn

Figure A.4
ADAC test vehicle approaching a stationary object

The tests revealed a large difference in performance between the tested models, with the Volvo City Safety system with head-up display rated "very good" and the Infiniti M rated "satisfactory". Several of the manufacturers have since announced improvements to their systems. The Infiniti has an active accelerator that gives haptic feedback by pushing against the driver's foot but ADAC noted that it requires further development.

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Appendix B – Accounting for the movements of vehicles to other jurisdictions when estimating crash numbers amongst a cohort of vehicles

A technical problem arises when crash data from a single state of Australia are used to estimate crash numbers experienced by a cohort of vehicles sold in that state. If a vehicle is transferred out of the state during the vehicle's service life they are 'lost' to the system being measured by the crash data from a single state, although such vehicles have the potential to continue to crash for the remainder of their service lives. This means that, as a cohort of vehicles age, there is the potential for growing mismatch between the numerator in the calculations of the average present value of crash costs (based on crashes occurring within a state) and the denominator (the number of vehicles in the cohort). This particular problem can be overcome to a large extent by estimating the rate at which vehicles enter or leave the state, and adjusting crash numbers to reflect this movement of vehicles.

Vehicle census data from the Australian Bureau of Statistics was used to assemble a time series of passenger vehicle numbers, by year of manufacture (with each year of manufacture constituting a cohort) separately for New South Wales and Australia. The number of vehicles can be extracted for cohorts starting with the 1991 cohort (vehicle numbers are aggregated prior to 1991) for each year since 2003, inclusive.

These data were used to establish apparent survival functions for Australia and New South Wales. The survival functions describe the proportion of vehicles that remain in a jurisdiction from one year to the next. The survival function for the whole of Australia can be used to approximate the scrappage rate of vehicles in Australia, while the survival function for New South Wales is a function of both the scrappage rate and the rate at which vehicles are transferred to or from other states in Australia. Therefore, the difference between both survival rates is the net rate at which vehicles are leaving New South Wales while remaining in service.

Because the census data begin in 2003, they contain only fragments of the population of vehicles in each cohort. For the present purpose it will be assumed that the apparent failure rate (the proportion of a cohort in one census year disappearing from the next census year) is primarily a function only of age, not of cohort or period. With this assumption it is possible to calculate the average failure rate with age over all fragments.

The results of this analysis are shown in Figure B.1. The results indicate that beyond the age of ten, a net ten per cent of vehicles originating in New South Wales are in service in another state or territory of Australia.

In the crash data analysis, the estimate of the number of vehicles operating outside of New South Wales (the solid line in Figure B.1) was used to adjust crash numbers upward, to reflect probable crash numbers involving vehicles operating outside of the state.

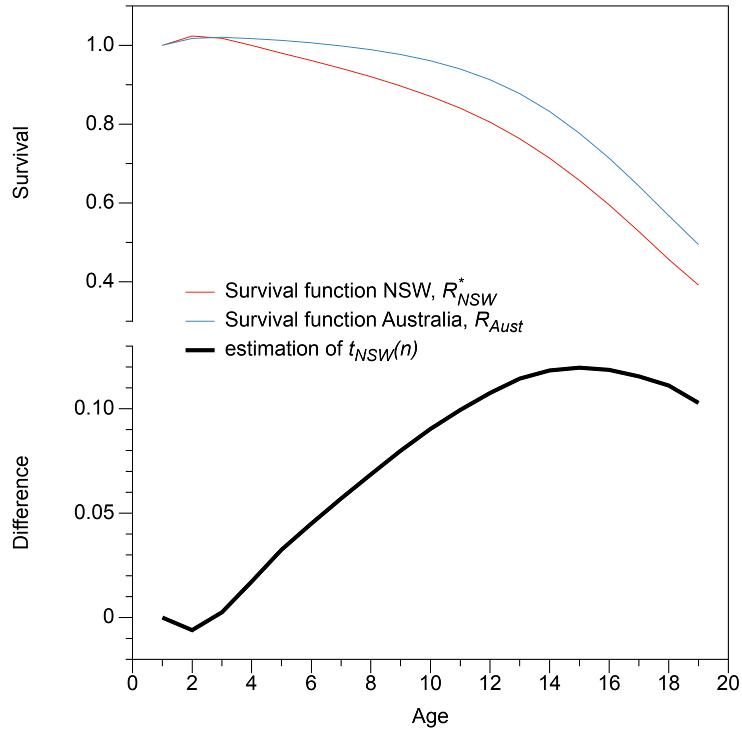

Figure B.1
Apparent survival function of vehicle in NSW and Australia and the difference

Appendix C– Discounted rates of crash involvement for vehicle cohorts from 2010 to 2020

Table C.1
Projected discounted crash involvement per 1000 vehicles for vehicle cohorts from 2010 to 2020, by crash type for passenger vehicles and overall for heavy vehicles

Speed limit	Crash severity	Type	Year of manufacture cohort										
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
50/60	Injury	Intersection	5.71	5.39	5.09	4.81	4.55	4.29	4.06	3.83	3.62	3.42	3.23
		Rear end	4.88	4.58	4.29	4.02	3.77	3.54	3.32	3.11	2.92	2.74	2.57
		Pedestrian	2.18	2.03	1.90	1.78	1.66	1.55	1.45	1.36	1.27	1.19	1.11
		Head on	0.44	0.40	0.37	0.34	0.31	0.28	0.26	0.24	0.22	0.20	0.18
		Hit fixed object	1.07	1.02	0.96	0.91	0.87	0.82	0.78	0.74	0.70	0.67	0.63
	Fatal	Pedestrian	0.040	0.037	0.034	0.031	0.028	0.026	0.024	0.022	0.020	0.018	0.017
		Hit fixed object	0.038	0.037	0.036	0.035	0.034	0.033	0.032	0.031	0.030	0.029	0.028
70/80/90	Injury	Rear end	2.27	2.15	2.05	1.95	1.85	1.76	1.67	1.59	1.51	1.43	1.36
		Pedestrian	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.08	0.08
		Hit fixed object	0.57	0.55	0.53	0.50	0.48	0.46	0.44	0.42	0.40	0.39	0.37
		Intersection	1.15	1.09	1.04	0.99	0.94	0.89	0.85	0.81	0.77	0.73	0.69
		Head on	0.26	0.24	0.22	0.21	0.19	0.18	0.17	0.15	0.14	0.13	0.12
	Fatal	Intersection	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
		Head on	0.034	0.031	0.028	0.026	0.024	0.022	0.020	0.018	0.017	0.015	0.014
		Hit fixed object	0.011	0.010	0.009	0.008	0.007	0.006	0.006	0.005	0.005	0.004	0.004
100/110	Injury	Head on	0.11	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03
		Rear end	0.48	0.46	0.45	0.43	0.41	0.39	0.38	0.36	0.35	0.33	0.32
		Hit fixed object	0.43	0.40	0.36	0.33	0.31	0.28	0.26	0.24	0.22	0.20	0.18
		Intersection	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03
	Fatal	Head on	0.056	0.051	0.047	0.043	0.039	0.036	0.033	0.030	0.028	0.025	0.023
		Hit fixed object	0.049	0.049	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Heavy vehicle	Injury	All FCAT relevant	30.4	27.6	25.1	22.9	20.8	18.9	17.2	15.7	14.2	13.0	11.8
	Fatal	All FCAT relevant	6.5	6.6	6.6	6.7	6.7	6.8	6.8	6.9	6.9	7.0	7.0