Austroads

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Safety Benefits of Cooperative ITS and Automated Driving in Australia and New Zealand

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Abstract

Two rapidly developing technology areas, Cooperative Intelligent Transport Systems (C-ITS) and Automated Driving applications, are reputed to have a substantial impact on road trauma through the increased use of technology both to assist drivers with the driving task, as well as providing enhanced crash avoidance capabilities. This project aimed to identify emerging C-ITS and AD applications and assess their potential safety benefits for Australia and New Zealand.

A comprehensive literature review and expert consultation found that C-ITS and AD were predicted to have significant potential to reduce road crash risk and injury consequences, with estimates varying widely between studies.

Using an analysis of Australian serious injury real-world crashes, expert estimates were made of the potential effectiveness of the following light passenger vehicle applications, as well as estimates of the annual savings in serious injuries Australia and New Zealand-wide.

Despite the clear potential benefits, several limitations were found that will need to be addressed before widespread implementation becomes possible.

Keywords

Cooperative Intelligent Transport Systems; Automated Vehicles, Road Safety, Human Factors, Implementation, Automated Driving

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About Austroads

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Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

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- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

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Summary

The emergence of Cooperative Intelligent Transport Systems (C-ITS) and Automated Driving (AD) applications is predicted to change the way in which drivers operate vehicles and move around on the road and are expected to have a range of road safety benefits.

Project Aims and Method

This project aimed to identify emerging C-ITS and AD applications and assess the safety benefits of a selection of those judged to have the greatest potential for Australia and New Zealand. A range of C-ITS and AD technology research documents were reviewed and policy experts from the UK, US and Europe were contacted and asked to provide information about current C-ITS and AD research activities, their thoughts on the likely deployment timelines and the key challenges (including human factors issues) to widespread adoption.

The literature review identified six major classes of C-ITS application, the first four of which were broadly defined as safety-based applications:

1. **Collision avoidance and hazard detection** (e.g. Intersection Movement Assist, Right Turn Assist, Queue Warning)
2. **Vulnerable road user safety** (e.g. Motorcycle Approaching Indication, Pedestrian Detection)
3. **In-vehicle signage** (e.g. Speed Zone Warning, Stop Sign Warning)
4. **Road weather alert systems** (e.g. Spot Weather Impact Warning)
5. **Post-crash notification systems** (e.g. eCall)
6. **Mobility and eco-driving** (e.g. Parking Spot Locator)

Based on the review outcomes, four connected and two automated technologies were selected and an analysis was undertaken using a random sample of relevant Australian serious injury real world crashes to make estimates of the serious injury reduction benefits for individual applications. The six applications selected for in-depth analysis were assessed as having a high potential to address major road trauma problems including carriage way departure crashes and intersection crashes. They were also selected due to their anticipated feasibility to deploy and availability in the vehicle market.

In general, it was assumed that all participating vehicles were equipped with the necessary technology, including suitably accurate positioning services, as well as the necessary roadside infrastructure. Expert estimates were then made of the potential effectiveness of key applications among light passenger vehicles. Finally, based on the Australian and New Zealand serious injury pool, estimates of the annual benefits of individual applications in isolation, if fitted to all light passenger vehicles.

Findings: Cooperative - ITS

While few crash reduction predictions have been determined to date, C-ITS has significant potential to reduce road crash risk and injury consequences. The literature review found that the National Highway Traffic Safety Administration (NHTSA) estimated that deployment of two V2V applications, intersection movement assist (IMA) and left turn assist (LTA) (RTA/Right Turn Assist in Australia and New Zealand) could prevent 41-55% of intersection crashes and 36-62% of right/left turn against crashes. European estimates suggest that C-ITS applications might yield up to a 16% reduction in fatalities and 9% of injuries, while Austroads previous estimates suggest reductions of 23% of fatalities and 28% of injuries under an aggressive introduction scenario.

The analysis of Australian real-world crash types demonstrated the following reductions in targeted crash types, and serious injuries based on four C-ITS applications:

C-ITS Application	Type	Crash types	Reduction in targeted crash type	Projected annual savings in FSI crashes (Australia)	Projected annual savings in FSI crashes (New Zealand)
Cooperative Forward Collision Warning (CFCW)	V2V	Same direction	20-30%	515-805	15-25
Curve Speed Warning (CSW)	V2I	Run-off-road, head-on (major roads)	20-30%	75-115	10-20
Intersection Movement Assist (IMA)	V2V	Adjacent direction	35-50%	940-1470	70-110
Right Turn Assist (RTA)	V2V	Right turn against	25-40%	525-825	25-55

A range of limitations for C-ITS were identified, primarily related to the level of digital infrastructure required for them to operate as predicted. The ready availability of high accuracy positioning, low latency communications and the necessary interoperability between devices was identified. Concerns with security and privacy impacts from C-ITS which require a new framework before wide-spread deployments can occur. It was also noted that C-ITS applications only provide driver alerts or warnings at this stage, requiring a driver to intervene. As this technology converges with automated driving, it is expected to be able to intervene in vehicle control systems to prevent crashes.

Due to the complexity of establishing a C-ITS operating environment, there are currently no vehicles available on the market with C-ITS equipment in Australia and New Zealand. One expert noted that eCall has already been the first wide-scale deployment of a C-ITS application in Europe and the UK. However, more complex V2V applications are still to emerge beyond field trials. The United States Department of Transportation has proposed to make V2V equipment a mandatory requirement from 2021. One European expert reported that initial deployment of cooperative vehicles would begin as soon as 2019.

Findings: Automated Driving

Automated driving applications perform one or more aspects of vehicle control (e.g. acceleration, braking, steering) without driver intervention and are expected to confer significant safety benefits, particularly as the level of automation increases. The US Federal Highway Administration predicted that 50-80% of highway crashes could be eliminated with the introduction of Automated Highway Systems (AHS). Automated Emergency Braking (AEB), for example, has been demonstrated to reduce all rear-end crashes by between 35% and 41%.

The analysis of Australian real-world crash types demonstrated the following reductions in targeted crash types, and serious injuries based on two automated driving applications:

Automated Driving Application	Type	Crash types	Reduction in targeted crash type	Projected annual savings in FSI crashes (Australia)	Projected annual savings in FSI crashes (New Zealand)
Lane Keeping Assist (LKA)	Automated	Run-off-road, head-on	25-40%	1415-2210	160-245
Auto Emergency Braking (AEB)	Automated	Same direction	35-50%	1195-1865	35-55

It is recognised that more highly automated driving will essentially be achieved through the packaging of several applications operating in tandem, including some or all of those evaluated in this study plus adaptive cruise control, with speed sign recognition, automated emergency steering and potentially others. The overall benefits will be considerably more than the benefits afforded by individual applications, but estimating the magnitude of these benefits, both in the long term as well as through the decades-long adoption phase, was beyond the scope of this study.

The experts consulted agreed that deployment timelines will depend on automation level, the complexity of the driving environment and road types. It was thought that once automated technologies are shown to work reliably public adoption will be rapid, although the infrastructure required to support highly automated driving will not be available for all conditions and locations. Fewer limitations were recognised for the automated vehicle applications, reflected in their current rapid levels of take-up in the fleet. For current market-deployed vehicles with Lane Keep Assist, limitations that were identified include the need for supporting infrastructure including physical infrastructure such as highly visible lane markings. In some vehicle models, drivers must also actively choose to enable these features on start-up.

At higher levels of automation, digital infrastructure such as more accurate positioning, high definition three-dimensional road mapping and cellular network coverage were identified as early system limitations, although these are still being explored through trials. A new policy and legal framework is also required before the widespread deployment of higher levels of automated driving can be achieved.

Lane Keep Assist and automated emergency braking features were found to already be widely adopted in the new vehicle market. However, timescales for uptake in the on-road or ‘in-service’ vehicle fleet show that it will take around 25 years to reach close to full penetration levels under as business as usual (un-regulated) market environment.

Findings: Human Factors (C-ITS and Automated Driving)

The literature also found that the potential safety benefits of C-ITS and automated driving may be limited by a range of human factors issues, leading to changes in driver behaviour not always able to be anticipated by vehicle and system designers. Some of the human factors issues included:

- Technology over-reliance, causing issues when drivers are required to regain vehicle control or use a non-equipped vehicle;
- Driver overload from system status monitoring, or underload or loss of vigilance potentially leading to reduced situation awareness and difficulties coping with sudden demand increases, such as during resumption of manual control. Issues with loss of vigilance and situation awareness may be particularly apparent with SAE Level 3 or ‘conditional automation’;
- Driver distraction when startled by alerts, having their attention drawn away from critical information or when engaging in distracting activities while in charge of an automated vehicle;
- Drivers failing to trust and/or accept the technology, leading to system misuse or disuse;
- Loss of driver skill, leading to problems in the event of automation failure and resumption of manual control.

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1. Introduction

1.1 Project Background

Smart vehicles that can communicate with each other, road infrastructure and other road users, provide driver assistance and potentially automate some or all aspects of the driving task will be increasingly introduced on roads overseas and in Australia and New Zealand over the next few decades. These technologies, termed Cooperative Intelligent Transport systems (C-ITS) and Automated Driving (AD) are predicted to have a range of safety, mobility and environmental benefits. A range of projects are underway in the United States and Europe to assess the safety benefits of C-ITS and AD applications and forecast deployment timelines. However, there is little known about the estimated safety benefits of these applications in Australia and New Zealand or the expected timing for fleet uptake.

This project aims to identify emerging C-ITS and automated driving applications and assess their potential safety benefits across a range of crash types and road scenarios and deployment timing for Australia and New Zealand, as well as identifying key issues that need to be addressed to support optimal deployment.

The project has four stages:

1. Review relevant international research on the estimated safety benefits of emerging C-ITS and AD applications and predicted deployment timelines;
2. Consult with government and industry stakeholders to obtain their expert opinions on the provision, implementation, regulation and use of C-ITS and AVs in Australia and New Zealand as well as internationally;
3. Using in-depth and mass crash data, evaluate the potential safety benefits across time of selected C-ITS and AD applications in relation to a range of crash scenarios; and
4. Identify pertinent issues necessary to be addressed for the successful deployment of C-ITS and AD applications in Australia and New Zealand.

This report commences with a review of the international research literature on emerging C-ITS and AD applications, with a focus on the estimated safety benefits of key applications across a range of crash types (where available). Also briefly reviewed are anticipated human factors issues or unintended consequences of C-ITS and AV technology (i.e. behavioural adaptation, driver trust, over-reliance, loss of vigilance and regaining manual control) and predicted timeframes for implementation, including the barriers to deployment. The review will largely concentrate on light vehicles as these are the focus of many of the major demonstration projects and constitute half of all serious trauma in Australia (Henley & Harrison, 2012); however, where available, C-ITS and AD applications will also be discussed for heavy vehicles and vulnerable road users such as pedestrians, cyclists and motorcyclists. The first section concludes with a discussion of the outcomes of the consultation with the C-ITS and AV research, industry and Government stakeholders.

The second major component of this project was to estimate the benefits of a set of key technologies flagged with the potential to have significant benefits to serious road trauma in Australia and New Zealand.

2. Review Of C-ITS and Automated Driving Research

2.1 Review Method

The first stage of the project reviewed the up-to-date international literature on emerging C-ITS and AD technologies to identify what systems are currently available or being developed, their actual or predicted safety benefits, any unintended consequences of their use on driver behaviour, and the predictions being made regarding likely timeframes for implementation.

A range of databases and resources were searched as part of the review: SafetyLit, ScienceDirect, TRID (the TRIS and ITRD combined database), TRANSPORT, Ingentaconnect, and Tandfonline, as well as search engines Google and Google Scholar. Key ITS and transport websites were also reviewed, including ITS Australia, ITS America, ITS Europe (Ertico), ITS UK, US Department of Transportation (ITS Joint Program Office), National highway Traffic Safety Administration (NHTSA), EC Europa as well as the major C-ITS and AV project websites. The search terms used were: Cooperative-ITS, Connected vehicles, V2V, V2I, V2X, Automated vehicles, Autonomous vehicles, Self-driving vehicles, and Driverless cars/vehicles, combined with terms such as Safety, Deployment, Implementation, and Human factors.

2.2 Overview of C-ITS and Automated Driving

Vehicles are becoming increasingly smarter with emergence of C-ITS and AD technology. Both forms of technology will change the way vehicles are operated and move around on the road. While C-ITS and AD technologies are typically discussed and examined independently, it is recognised that the two areas are heavily intertwined and C-ITS is anticipated to increasingly converge with and support higher levels of automation. For ease of distinction, however, C-ITS and AD will be discussed separately in this report.

C-ITS technologies rely on wireless communication with other vehicles (V2V), infrastructure (V2I) or with anything including V2V, V2I, pedestrians, Cloud based services and mobile devices such as smartphones (V2X) to warn drivers or to potentially intervene in dangerous situations, reduce traffic congestion and increase system efficiency, among other applications. By using wireless communications to enable systems to work cooperatively, C-ITS aim to address some of the biggest surface transportation challenges and are expected to have a range of benefits, including enabling safer vehicles and roads, enhancing mobility and reducing environmental impacts. Of particular relevance is that, as well as enhancing the benefits provided by existing standalone systems, C-ITS also can offer warnings that are not currently available with standalone systems, such as intersection-based warnings and right turn assistance.

Safety-related C-ITS applications are likely to communicate via the use of Dedicated Short Range Communications (DSRC), although other communications technologies are also being examined, such as cellular, Wi-Fi and satellite (Barbaresso et al., 2014). DSRC allows reliable, highly secure, high-speed and low latency communication between similarly-equipped vehicles and between vehicles and infrastructure via short-to-medium range wireless communication channels. A range of jurisdictions including the United States, Europe and Japan have reserved the 5.9 GHz band (5.8 GHz in Japan) for safety related ITS applications and there is a significant amount of work underway to standardise C-ITS communication technology.

There are also significant steps being taken towards the development of automated or self-driving cars. Already there are a number of vehicles on the road that allow for some degree of lateral and longitudinal control to be shifted from the driver to the vehicle, for example with the use of a combination of adaptive cruise control, automatic braking and lane keeping assistance systems. A system of (non-hierarchical) levels of automated driving have been defined. According to the Society of Automotive Engineers' international standard SAE J3016, the lowest level (Level 0) no automation, is where the driver is in control of all aspects of the driving task. The five remaining levels address increasing levels of driver assistance from Level 1 to 5, as shown in Figure 2.1 below (for more detail explanation of each automation level see Section 2.4). Level 2 or partial automation (SAE J3016; SAE, 2014) has been available in Australia since 2013, vehicles with Level 3 capability (conditional automation) are predicted to be introduced to markets by 2020 (Trimble et al., 2014). Vehicles with Level 3 capability provide automatic longitudinal and lateral control in certain driving scenarios and the vehicle is responsible for monitoring the environment while in an automated mode. The role of the driver is to receptive to any requests to intervene in the driving task by the automated driving system. This includes being available to take back vehicle control if requested (SAE J3016).

Figure 2.1: SAE J3016 (September 2016), Levels of driving automation

Level	Name	Narrative definition	*DDT*		*DDT fallback*	*ODD*
			Sustained lateral and longitudinal vehicle motion control	*OEDR*		
Driver* performs part or all of the *DDT						
0	No Driving Automation	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	Driver Assistance	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	Partial Driving Automation	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
ADS* ("*System*") performs the entire *DDT* (while engaged*)						
3	Conditional Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	High Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	Full Driving Automation	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

ADS: Automated Driving System; DDT: Dynamic Driving Task; ODD: Operational Design Domain; OEDR: Object and Event Detection and Response

Like C-ITS, AD technology is predicted to have a range of safety benefits, primarily by reducing driver workload and human error. However, with both types of technology there are substantive technical, operational, legal and human factors challenges to address before cooperative and automated systems are implemented on a wide scale. The remaining sections of this report identify emerging C-ITS and AD technologies, discuss what is currently known about their estimated safety benefits and estimated timelines to deployment, and cover some of the human factors challenges associated with the introduction of these systems.

2.3 Cooperative Intelligent Transport Systems

2.3.1 Identification of Emerging C-ITS Applications

Six major classes of C-ITS applications were defined from the literature by the research team based on the range of different surface transport problems each class seeks to address. These include:

1. Collision avoidance and hazard detection
2. Vulnerable road user safety
3. In-vehicle signage
4. Road weather alert systems
5. Post-crash notification systems
6. Mobility and eco-driving

This review will focus on the first five application classes, which can all broadly be defined as safety-based C-ITS applications, although mobility and eco-driving applications will also be briefly discussed. A range of individual systems are being developed within each class (see Table 2.1 for examples of key applications). These are further grouped according to communication method, whether V2V, V2I or V2X, although some technologies can fall across multiple communication methods. Functional descriptions of key technologies that have been flagged as priority systems for deployment by various jurisdictions or are the focus of major demonstration projects from each class are presented in Tables 2.1 to 2.7.

Table 2.1: Matrix of example V2V, V2I and V2X C-ITS applications

C-ITS Application	V2V	V2I	V2X
Collision Avoidance & Hazard Detection	• Intersection Movement Assist (signalised and unsignalised) • Left (Right) Turn Assist • Cooperative Forward Collision Warning (slow vehicle warning, stationary vehicle warning) • Electronic Emergency Brake Lights • Overtake/Do Not Pass Warning • Blind Spot/Lane Change Warning • Emergency Vehicle Approach Warning	• Red Light Violation Warning • Stop Sign Violation Warning • Rail Level Crossing Warning • Curve Speed Warning • Roadworks Warning • Incident Warning • Reduced Speed Zone Warning • Wrong Way Driving Warning • Low Structure Warning • Queue Warning	

C-ITS Application	V2V	V2I	V2X
Vulnerable Road User Safety	• Motorcycle Approaching Indication	• Illumination on Demand Module (pedestrians)	• Pedestrian Detection • Intelligent Pedestrian Traffic Signal • Mobile Accessible Pedestrian Signal System • Cooperative Intersection Safety for cyclists • Cooperative Intersection Safety for pedestrians
In-vehicle Signage		• Speed Zone Warning • Stop Sign Warning • Service Signs • Directional Signs	
Road Weather Alert Systems		• Spot Weather Impact Warning • Road Surface Condition Warning	
Post-Crash Notification Systems		• eCall • Advanced Automatic Crash Notification (AACN)	
Mobility & Eco-driving	• Cooperative Adaptive Cruise Control	• Dynamic Speed Harmonisation • Signal prioritisation of public transport, emergency vehicles, freight vehicles, eco-vehicles • Energy efficient intersection services • Parking Spot Locator	• Advanced Traveller Information Systems • Vehicles as probes (collect network wide traffic information fed back to traffic management) • Parking Spot Locator (using Cloud)

Source: US Department of Transportation ITS Joint Program Office: http://www.its.dot.gov/pilots/cv_pilot_plan.htm and http://www.iteris.com/cvria/html/applications/applications.html

Collision Avoidance and Hazard Detection

Collision Avoidance and Hazard Detection C-ITS applications are aimed at improving road safety by automatically recognising and avoiding hazards that the driver either fails to detect or detects too late to take successful evasive action, either because they have been distracted, inattentive or overloaded, or the hazard is out of the driver’s line of sight. By using vehicle sensors and communicating with roadside infrastructure, these applications build a form of situation awareness of surrounding vehicles to warn drivers of potentially dangerous situations or intervene to avoid a collision. A range of collision avoidance and hazard detection C-ITS applications have been developed or are emerging (see Table 2.1). Some of the key applications that are either fitted to commercial vehicles or are currently being (or have been) trialled as part of demonstration projects are described in Table 2.2.

The predicted safety impacts listed in Tables 2 to 7 are subjective judgements based on a combination of the likelihood of the targeted problem and the typical outcome severity for those involved in a typical crash. These are not intended to be conclusive at this stage, but will be used to indicate which applications might warrant being considered in greater depth, as documented in Section 4. The key crash types addressed by each application are also subjective judgements and use the main Definitions for Coding Accidents (DCA) code groups.

Table 2.2: Functional description of key collision avoidance and hazard detection C-ITS applications and their predicted safety impact

Application	Functional description	Key Crash Types Addressed[1]	Predicted Safety Impact
Intersection Movement Assist (IMA)	IMA uses V2V communication to exchange current vehicle location, direction and motion information to warn the driver when it is not safe to enter an intersection due a high risk of collision with another vehicle. This application can operate at both signalised and unsignalised intersections. Information from on-board sensors (e.g. radars and image processing) can also be used, if available, in combination with V2V communications to detect non-connected vehicles.	Adjacent Direction	High
Right Turn Assist (RTA)	RTA uses V2V communication to warn the driver when there is strong probability they will collide with an oncoming vehicle while making a right hand turn at signalised [2]and unsignalised intersections. This application is particularly useful when a driver's view of oncoming vehicles is blocked by other vehicles, road curvature or infrastructure.	Opposing Direction	High
Cooperative Forward Collision Warning (CFCW)	CFCW uses V2V communication to detect a direct and imminent threat ahead of the host vehicle and warns the driver in order to avoid or reduce the severity of crashes into the rear of other vehicles travelling in the same lane. This application can warn of stationary or slow moving vehicles ahead.	Same Direction	Medium
Electronic Emergency Brake Light (EEBL)	EEBL issues a warning to the driver to act when a V2V equipped lead vehicle that may be out of their line of sight is decelerating rapidly. This application allows drivers advanced warning of events occurring in the traffic stream ahead that they would otherwise not be able to detect due to visual obstructions like other traffic or poor weather.	Same Direction	Medium
Overtake/Do Not Pass Warning	The do not pass system uses V2V communication to provide a warning to drivers when it is unsafe for them to overtake a slower vehicle because vehicles are approaching in the opposite direction. This system usually only issues a warning when the turn signal is activated and, thus, does not address situations when the vehicle unintentionally drifts into the on-coming lane.	Overtaking Opposing Direction	Medium
Blind Spot/Lane Change Warning (BSW)	Cooperative BSW enhances the capabilities of existing standalone BSW systems by using V2V communication to detect vehicles in the adjacent lane that are in or approaching the host vehicles blind spot and provides an alert if the driver attempts a lane change. This system typically issues a warning only when the turn signal is activated and, thus, does not address situations when the vehicle unintentionally drifts into an adjacent lane.	Same Direction	Medium
Emergency Vehicle Approach Warning	This application provides alerts to drivers about the location and movement of emergency response vehicles so that drivers have advanced opportunity to move out of the vehicles path.	Adjacent Direction Opposing Direction Same Direction	Low
Red Light Violation Warning	Uses V2I communication to determine if a vehicle is at risk of running a red light and if so, providing a warning. Traffic light signal logic can also be used to determine if an extension of a red phase for intersecting roads is warranted to avoid a potential collision.	Adjacent Direction	Medium

1 Crash types from the high-level DCA (Definitions for Classifying Accidents) categories used by VicRoads
2 Some sources describe this technology as targeted at uncontrolled turns across traffic, however as it is generally activated with the vehicle indicators, there seems no reason why it could not function equally well at signalised intersections. See http://www.sae.org/mags/sve/NEWS/9888 for example.

Application	Functional description	Key Crash Types Addressed[1]	Predicted Safety Impact
Rail Level Crossing Warning	Uses V2I communications to exchange information about the location and motion of vehicles and trains near rail level crossings and provides a range of advanced warnings to drivers including information about approaching trains, possible conflicts between the train and the vehicle, faulty crossings and expected delays at crossings.	Passenger and Miscellaneous (Struck train/crossing furniture) Adjacent Direction	Medium
Curve Speed Warning	The curve speed warning system uses V2I communication to exchange information about road geometry, current weather and individual vehicle performance characteristics to determine, for each individual vehicle, the appropriate speed to safely negotiate the curve.	Off path on curve Opposing Direction (head-on)	Medium
Roadworks Warning	Uses portable roadside equipment to transmit speed limit or work zone information to approaching V2I equipped vehicles. The vehicle then issues alerts regarding any action required such as the need to reduce speed, change lanes, detour or stop. Similar applications have been developed to warn of an incident on the roadway (e.g. collision, burst water main, breakdown) that requires drivers to take some sort of action.	Same Direction On Path	Low
Queue Warning	This application uses V2V and V2I communication to allow equipped vehicles in a queue to automatically broadcast their queue status to surrounding upstream vehicles and to infrastructure such as Traffic Management Centres. Alerts are then provided to approaching vehicles to avoid incidents such as rear end crashes or to allow drivers to seek an alternate route.	Same Direction	Low

Note: Safety impacts in this table are qualitative, based on engineering judgement and will be assessed in greater detail in subsequent stages of this project.

Vulnerable Road User Safety

A range of C-ITS applications have been developed to specifically meet the needs and transport issues faced by vulnerable road users (VRUs), including pedestrians, cyclists and motorcyclists. This class of applications are aimed at improving the safety of VRUs by alerting drivers to their presence, particularly if they are out of the driver's line of sight, and giving them priority at crossings so they are less likely to come into conflict with vehicles. Some key VRU C-ITS applications that have been or are currently being trialled as part of demonstration projects, such as the VRUITS project (Gonzalez et al., 2015), are described in Table 2.3.

Table 2.3: Functional description of key VRU C-ITS applications and their predicted safety impact

Application	Functional description	Key Crash Types Addressed	Predicted Safety Impact
Pedestrian Detection	Pedestrian detection applications use either V2I communication (e.g. roadway sensors) or V2X communication (e.g. mobile devices such as the pedestrian's phone) to detect the location of pedestrians beyond the driver's line of sight and warn the driver of their presence and location. Variants of this application can also illuminate the crossing and surrounding areas to increase the conspicuity of pedestrians (Illumination on Demand Module).	Pedestrian Crashes	Medium
Intelligent Pedestrian Traffic Signal	This application acts as a traffic signal control system that uses roadway sensors to detect the presence of pedestrians wanting to cross a crossing and calls for a green pedestrian signal. Sensors in the crossing can also detect the speed of the pedestrian and adjusts the timing of the green phase so that slower pedestrians have time to cross. The system can also automatically cancel the pedestrian green phase if the pedestrian leaves the detection area. A V2X variant also allows pedestrians to activate a green	Pedestrian Crashes	Low

Application	Functional description	Key Crash Types Addressed	Predicted Safety Impact
	crossing phase via their mobile device.		
Mobile Accessible Pedestrian Signal System (MAPS)	MAPS uses V2X communications to assist pedestrians with limited or no eyesight to cross signalised intersections safely by using audio signals on a smartphone to indicate the desired travel direction and provide street name and direction when at an intersection. Audible messages are also provided to indicate that the crossing signal has been requested and how long until the green phase.	Pedestrian Crashes	Low
Cooperative Intersection Safety for cyclists	This application uses V2X communication (roadside radar unit, cyclist communication unit and on-board equipment in vehicles) to detect cyclists near a crossing that is outside of the driver's field of view and send information to drivers about the position and speed of the cyclist. If a collision is deemed likely, the system sends a message to warn the driver and the cyclist.	Adjacent Direction Manoeuvring	Low
Motorcycle Approaching Indication	This application uses V2V communication to warn the driver of a vehicle that a motorcycle is approaching either from behind, in front or from the left or right at an intersection.	Adjacent Direction Opposing Direction Same Direction	Medium

Note: Safety impacts in this table are qualitative, based on engineering judgement and will be assessed in greater detail in subsequent stages of this project.

In-Vehicle Signage

In-vehicle signage augments road-based signs and aims to increase drivers' awareness of certain information or situations in case a roadside traffic sign is not noticed, understood or heeded. In-vehicle signage can include static sign information (e.g. speed limit, direction signs, stop signs) and dynamic information (e.g. rail level crossing status, weather warnings, emergency vehicle warnings). Several key static in-vehicle signage applications are defined in Table 2.4, while key dynamic in-vehicle signage is discussed under other C-ITS application classes (e.g. weather systems and rail level crossing warnings).

Table 2.4: Functional description of key in-vehicle signage C-ITS applications and their predicted safety impact

Application	Functional description	Key Crash Types Addressed	Predicted Safety Impact
Speed Zone Warning	Speed Zone Warning systems display the current posted speed limit on an in-vehicle display and warn drivers when they have entered a new speed zone or have exceeded the limit for a zone. These systems usually include dynamic speed information about speed limits that change at certain times of day (e.g. school zones) or that are transient changes (e.g. around roadwork).	Same Direction Opposing Direction Off Path Pedestrian, etc.	Medium
Stop Sign Warning	This application aims to improve safety at unsignalised intersections with stop signs by providing an in-vehicle warning to approaching drivers that they may violate an upcoming stop sign based on their speeds and distance to the sign.	Adjacent Direction	Low

Note: Safety impacts in this table are qualitative, based on engineering judgement and will be assessed in greater detail in subsequent stages of this project.

Road Weather Systems

Road weather C-ITS applications assess, forecast, and address the impacts that weather has on travel and safety. They are designed to warn drivers of potentially hazardous driving conditions due to poor weather or road surface conditions. Two key applications are spot weather impact warning and road surface condition warning systems (Table 2.5).

Table 2.5: Functional description of key road weather C-ITS applications and their predicted safety impact

Application	Functional description	Key Crash Types Addressed	Predicted Safety Impact
Spot Weather Impact Warning	This application uses real time weather data collected via probe vehicles, weather services or road side weather services (ice detection, surface water detection) to alert drivers to unsafe conditions or road closures at certain points on the roadway because of weather conditions, including ice, fog, heavy rain or high winds.	Same Direction Opposing Direction Off Path	Low
Road Surface Condition Warning	This application can provide drivers with advanced warning that they are approaching an area that contains changed surface conditions such as gravel road, or hazards such as pot holes and broken paving.	Opposing Direction Off Path	Low

Note: Safety impacts in this table are qualitative, based on engineering judgement and will be assessed in greater detail in subsequent stages of this project.

Post-Crash Notification Systems

Post-crash notification or 'Mayday' systems are designed to reduce the impact of road trauma by reducing the time between the crash occurring and when medical services are provided. Information about the crash is automatically sent to a call centre or emergency responders. Examples of post-crash notification systems that have been trialled or are planned for implementation are presented in Table 2.6.

Table 2.6: Functional description of key post-crash notification C-ITS applications and their predicted safety impact

Application	Functional description	Key Crash Types Addressed	Predicted Safety Impact
Post-crash notification	In the event of a crash, post-crash notification systems, such as eCall (Europe) and the Automated Collision Notification (ACN) (US), automatically trigger a voice connection to relevant emergency services and transmit an emergency message containing a ‘minimum set of data’ including time and location of the crash and information about crash severity.	All types	Low-Medium[3]

Note: Safety impacts in this table are qualitative, based on engineering judgement and will be assessed in greater detail in subsequent stages of this project.

[3] Overall effect. Will be higher for single vehicle crashes in rural and remote areas.

Mobility and Eco Driving Systems

In addition to enhancing safety, a key aim for C-ITS is to improve traffic mobility and efficiency and reduce the environmental impacts of the ever-expanding transport system. By using V2V, V2I and V2X communications, these applications can continuously exchange information about traffic movements and congestion across an entire road network, not just individual locations, and offer motorists alternative routes or courses of action to improve the flow of the traffic and drive in a more eco-friendly manner. A range of C-ITS exist within the mobility and environmental domain (Table 2.7).

Table 2.7: Functional description of key mobility and eco-driving C-ITS applications and their predicted safety impact

Application	Functional description	Key Crash Types Addressed	Predicted Safety Impact
Cooperative Adaptive Cruise Control	Cooperative adaptive cruise control (CACC) is an evolution of Adaptive Cruise Control (ACC) that allows wireless V2V communication to automatically synchronize the movements of many vehicles within a platoon, thereby improving the stability of traffic flow. CACC will form a key element of truck platooning (see Section 2.4).	Same Direction	Medium
Dynamic Speed Harmonisation	This application aims to maintain consistent speeds and reduce unnecessary stops and starts on sections of road approaching areas of traffic congestion, such as bottlenecks, shopping strips and events. The application uses V2I communication to determine speed recommendations based on traffic conditions and weather information and broadcasts speed recommendations to connected vehicles or via roadside signs for unconnected vehicles.	Same Direction	Low
Traffic signal prioritisation	Traffic Signal Prioritisation applications use V2I communication to allow certain classes of vehicles to request priority at intersections reducing the amount of time they spend at red lights. Applications have been developed that allow public transport, emergency vehicles, freight vehicles and eco-vehicles to request priority signals.	Adjacent Direction	Low
Advanced Traveller Information Systems (ATIS)	ATIS applications allow the collection and exchange of a wide range of transportation information, including traffic flow, road weather, roadwork, and incident data. Information is broadcast in-vehicle or via roadside signs so that drivers can make informed decisions about a trip, such as the best transport mode or route to take and the estimated time it will take.	N/A	-
Parking Spot Locator	These applications use V2I or V2X communications to provide information to drivers on the number and location of unoccupied parking spaces when entering a car park or area.	N/A	-

Note: Safety impacts in this table are qualitative, based on engineering judgement and will be assessed in greater detail in subsequent stages of this project.

2.3.2 Estimated Safety Benefits of C-ITS

While a small number of C-ITS applications have been introduced into some segments of the current vehicle fleet, they have not yet been deployed in large enough numbers and over a long enough period for crash numbers to be a reliable indicator of their safety benefit. However, a few large-scale C-ITS demonstration projects have or are being conducted worldwide that will start to shed some light on the possible safety benefits of C-ITS (see Appendix A for a list of major international C-ITS projects). While there has only been a handful of crash reduction results derived from the large-scale C-ITS field operational tests (FOTs) to date, there is a high level of confidence that C-ITS applications have significant potential to reduce crash risk and the injury consequences of road crashes. A range of studies from Europe, United States, Australia and New Zealand have estimated the number of road crashes that will be addressed using various C-ITS applications either using mass crash data, modelling (i.e. micro simulation) using FOT data as input, or using FOT data directly to estimate the crash reduction impact. However, to date most of these estimates are general estimates for bundles of C-ITS applications, although there are estimates available from the US for a small number of individual applications.

It is likely that the benefits in Australia and New Zealand will differ compared with those observed in other regions worldwide. Subsequent phases of this project will create estimates based on the Australia and New Zealand context and crash situation.

United States Estimates

In the United States, NHTSA estimated that deployment of two V2V applications, intersection movement assist (IMA) and left turn assist (LTA) (RTA in Australia), could prevent up to 592,000 crashes each year and up to 1,083 lives when fully deployed in the national fleet (Harding et al., 2014). On an individual basis, this project estimated that IMA would prevent 41 to 55% of IMA crashes and LTA would prevent 36 to 62% of LTA crashes.

As part of the IntelliDrive safety systems program, the Volpe National Transportation Systems Center in the US estimated the annual frequency of three different crash types that could potentially be addressed by the IntelliDrive V2V and V2I systems (Najm et al., 2010). The 2005 – 2008 General Estimates System crash database was used to estimate crash reductions for crash types involving light vehicles, heavy trucks and all vehicle crashes. They found that deployment of the IntelliDrive C-ITS systems and particularly the combined use of V2V and V2I applications have the potential to address a large percentage of police-reported crashes involving unimpaired drivers. It is important to note here, that the estimates relate to the percentage of target crashes that can potentially be *addressed* by C-ITS and do not necessarily make any estimates of *crash reduction* effect. Nonetheless, they are included here as an indication of the potential safety impact of various C-ITS application classes.

V2V systems can potentially address:

- 4,409,000 of police-reported (PR) or 79% of all vehicle target crashes annually
- 4,336,000 PR or 81% of all light-vehicle target crashes annually
- 267,000 PR or 71% of all heavy-truck target crashes annually.

V2I systems can potentially address:

- 1,465,000 PR or 26% of all-vehicle target crashes annually
- 1,431,000 PR or 27% of all light-vehicle target crashes annually
- 55,000 PR or 15% of all heavy-truck target crashes annually.

Combined V2V and V2I systems can potentially address:

- 4,503,000 PR or 81% of all-vehicle target crashes annually
- 4,417,000 PR or 83% of all light-vehicle target crashes annually
- 272,000 PR or 72% of all heavy-truck target crashes annually.

Most recently, researchers at The University of Texas have used the US General Estimates System crash records to estimate the economic and functional-years[4] crash-related savings expected from eleven connected and automated driving technologies, including Forward Collision Warning (FCW) combined with Cooperative Adaptive Cruise Control (CACC), and Cooperative Intersection Collision Avoidance Systems (Li & Kockelman, 2016). Estimates were calculated for three effectiveness scenarios (conservative, moderate and aggressive) and a market penetration rate of 90% for all applications. Combined, the connected and automated driving technologies were estimated to save between $127 and $151 billion in economic costs each year in the US and between 1,422,600 to 1,652,200 functional human-years per year. With respect to individual applications, the FCW combined with CACC had the greatest estimated potential, resulting in a saving of at least $53 billion per year and 497,100 functional years.

European Estimates

In Europe, the CODIA (Co-Operative Systems Deployment Impact Assessment) project assessed the safety impacts of five C-ITS systems in 2020 and 2030 with ‘low’ and ‘high’ market penetration scenarios, also forecasting the safety impacts at 100% penetration, independent of year. Technologies included: V2I dynamic speed adaptation, Reversible lane control, Local danger / hazard warning, Post-crash warning and Cooperative intersection collision warning (Kulmala, Leviakangas, et al., 2008; Kulmala, Rämä, & Sihvola, 2008). The dynamic speed adaptation system showed the greatest promise, estimated to reduce fatalities by 7.2% and injuries by 4.8% at 100% market penetration. The local danger warning application was expected to reduce fatalities by 4.2% and injuries by 3.1%, while the intersection collision warning system was estimated to reduce fatal crashes by 3.7% and injuries by 6.9%. The reversible lanes application was the only C-ITS examined that was not predicted to have an impact on fatalities or injuries.

The COoperative Benefits for Road Authorities study (COBRA) investigated the costs and benefits of deploying bundles of V2I cooperative systems (Ball, van Noort, & Nitsche, 2013; Malone, Hopkin, & Nitsche, 2014). As part of the project, the safety impacts of three bundles of C-ITS applications were estimated: ‘Local Dynamic Event Warnings’; ‘In-vehicle Speed and Signage’; and ‘Travel Information and Dynamic Route Guidance’. Impact was assessed for 100% penetration rates. It was predicted that the Local Dynamic Event Warnings and In-vehicle Speed and Signage bundles would each reduce the number of fatalities by 7%, while the Travel Information and Dynamic Route Guidance bundle would reduce fatalities by 4%. In terms of injury crashes, it was estimated that the In-vehicle Speed and Signage and Travel Information and Dynamic Route Guidance bundles would each prevent 5% of these crashes, while the Local Dynamic Event Warnings bundle would prevent 7% of injury crashes.

The safety impacts of C-ITS in Europe were also estimated for the year 2020 by the SAFESPOT project. Two cooperative system bundles were considered, each containing a number of applications: V2V (Lateral collision warning, Road departure warning, Longitudinal collision warning) and V2I (Cooperative intersection collision prevention and Hazard and incident warning) (Geissler, Schindhelm, & Luedeke, 2011; Schindhelm et al., 2010). The analysis assumed a 100 % penetration rate of the systems into the vehicle fleet. The impact analysis showed considerable safety effects resulting in an 8.9% reduction in fatalities (8.55% for injuries) for the V2I systems and a 7.1 % reduction in fatalities (7.3% for injuries) for the V2V systems.

Most recently, European C-ITS crash reduction estimates were derived from the DRIVE C2X Project, which provided a Europe-wide assessment of the safety and efficiency benefits of eight C-ITS applications. Field operational tests were conducted at seven test sites across Europe involving 750 drivers (Schulze et al., 2014). As part of the project, a safety impact assessment was conducted to examine the impact of the eight C-ITS applications on fatal and injury crashes for target years 2020 and 2030 (K. Malone et al., 2014). 100% infrastructure penetration was assumed and the findings are based on equipping passenger cars only. The assessed C-ITS applications included:

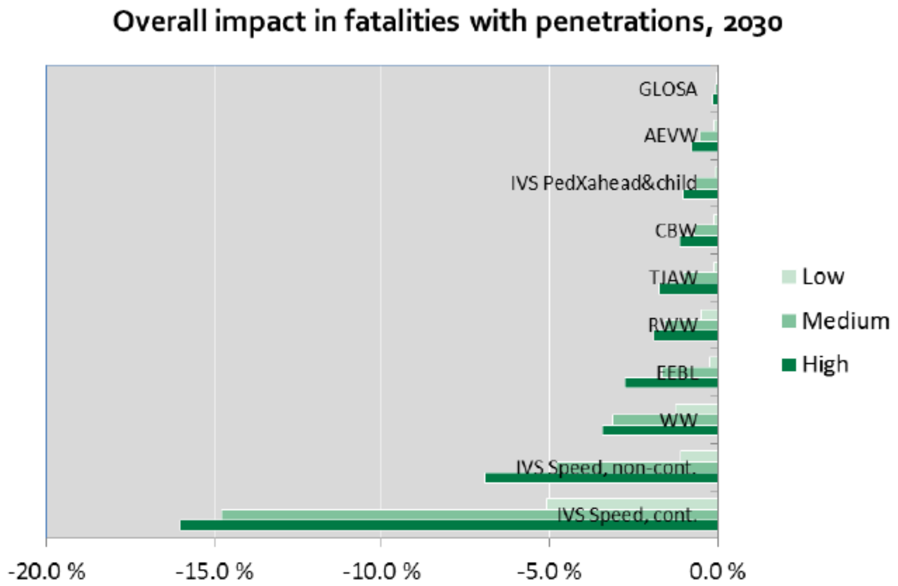
- Approaching emergency vehicle warning (AEVW)
- Car breakdown warning (CBW)
- Electronic emergency brake light warning (EEBL)

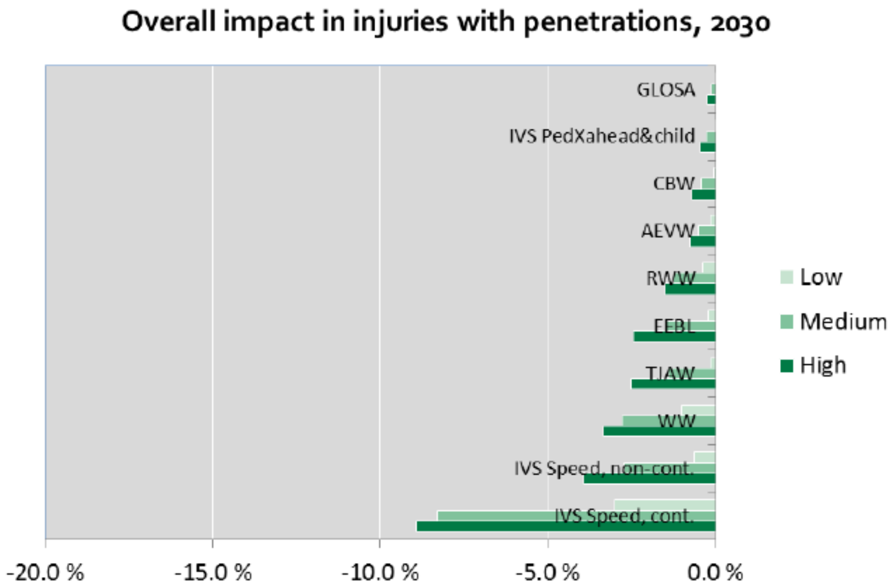
[4] Functional-years lost calculates the years of life lost due to fatal injury and the years of functional capacity lost due to non-fatal injuries

- Green light optimal speed advisory (GLOSA)
- In-vehicle signage (IVS) – speed limit (continuous and not continuous), Pedestrian crossing and Yield/Stop signs
- Road works warning (RWW)
- Traffic jam ahead warning (TJAW)
- Weather warning (WW)

Figure 2.2 displays the estimated safety impacts of the eight C-ITS applications from the DRIVE C2X Project in 2030 at different penetration levels. The most effective application from a crash reduction point of view was the IVS Speed limit, preventing up to 16% of fatalities and 8.9% of injuries. The other applications provided estimated fatality reductions of between 0.1 – 3.4% and injury reductions of 0.2 – 3.3%.

Figure 2.2: Estimated safety impacts of C-ITS from the DRIVE C2X Project in 2030 with vehicle penetration scenarios: low (19.88%), medium (68.68%) and high (75.60%)





Source: Malone et al. (2014)

Several studies have also estimated the safety benefits of automatic crash notification systems, such as eCall, which will be required to be fitted to all new models of vehicles launched in the EU from March 2018. An impact assessment of introducing eCall into all new vehicles in Europe found that the impact of reduced rescue time on fatalities differed by country due to individual geography and rescue service performance. For Finland, a reduction of 4-8% in road fatalities was estimated; however, the reduction in the UK was estimated to be considerably smaller at 1% (Francsics et al., 2008). More recently, a US study explored the effects of advanced automatic collision notification (AACN) and earlier emergency service times arrival on passenger/driver survivability using Fatality Analysis Reporting System (FARS) data from 2005 to 2009 (Wu et al., 2013). This study estimated that reducing crash notification time to one minute or less from the values in the sample selected from the FARS would reduce road fatalities by approximately 1.84% (around 700 annually).

Australian Estimates

In 2011, an analysis of the potential safety benefits of V2V collision avoidance technologies that use DSRC was conducted for Austroads (Taranto, Young, & Logan, 2011). Serious injury crash reduction estimates were provided for a range of crash types identified by DCA code (Definition of Classifying Accidents). A database of over 86,000 serious police-reported crashes spanning the period 2005-2007 inclusive was used. It was estimated that with widespread application of DSRC collision avoidance technologies, it is possible to prevent between 7,500 and 10,350 of the approximately 28,950 serious injuries experienced in Australia each year, representing a reduction of between 25% and 35%.

Researchers from the Centre for Automotive Safety Research (CASR) have also examined the safety potential of current commercially available C-ITS on-board units provided by Cohda Wireless (Doecke, Grant, & Anderson, 2015). These units included a threat detection engine that provides various levels of braking warnings to the driver. Data from CASRs in-depth crash investigations was used to simulate 89 real-world crashes. It was found that with the use of C-ITS technology, between 37% and 86% of the simulated crashes could be avoided, with the highest reduction estimated for a fully autonomous system braking at 0.7g as soon as the warning is issued and the lowest estimate for a system braking at 0.4g and a 1.2 sec reaction time to the warning.

Using effectiveness values from previous CASR research and re-running their simulations, the Royal Automobile Club of Victoria (RACV) estimated the crash reduction potential of AEB and V2V systems (with braking intervention) under aggressive, encouraged and slow introduction scenarios. They predicted that by 2030, combined use of AEB and V2V communications would reduce 23% of fatalities and 28% of injuries under an aggressive introduction scenario. Under an encouraged scenario, there would be a 17% reduction in fatalities and 20% reduction in injuries with combined use of the systems.

Impacts on Driver Behaviour

While not specifically part of the scope of this review, a range of studies have examined the impact of C-ITS applications on driver behaviour and these results have implications for the expected safety benefits of these technologies. These studies range from small-scale simulator studies, short-term instrumented vehicle studies to large-scale field operational tests and have demonstrated that the use of C-ITS can lead to a range of improvements in driver behaviour. These include:

- Slower approach speeds and greater compliance at stop signs (V2I stop sign recognition system) (Fukushima, 2011)
- Speed reductions, longer following distances and reduced driver stress after receiving advisory speed, congestion and incident alerts from a V2I Advanced Traveller Information System (Farah & Koutsopoulos, 2014; Farah et al., 2012)
- Significantly faster reaction times to steer away from a lateral crash threat after receiving a forward collision warning coupled with a lane change warning (Lerner et al., 2014)
- Driver reported high levels of effectiveness and adequate alert timing of a DSRC based V2V and V2I system to improve safety at rail level crossings (Singh et al., 2012; Singh et al., 2013)

2.3.3 Predicted Deployment Timelines for C-ITS

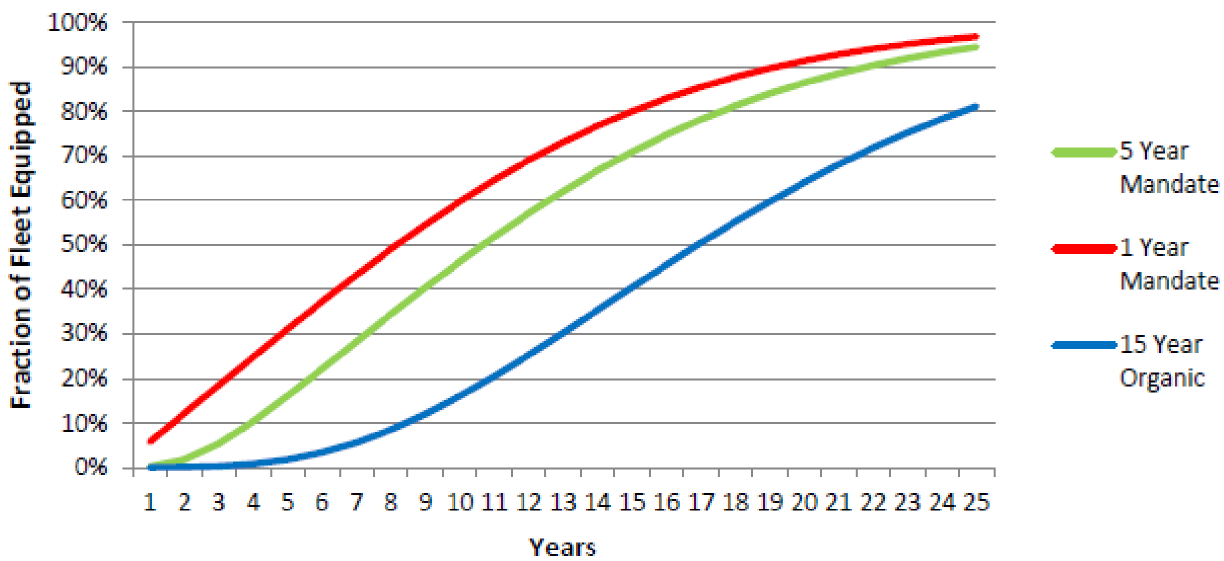
There are now concentrated efforts in many countries to implement the required infrastructure and policy and governance processes to deploy C-ITS applications on a wide scale. The United States, Japan and the European Commission have all signed agreements to develop coordinated research programs on C-ITS with the aim of avoiding the development of multiple standards, reducing costs and accelerating the adoption of cooperative systems. While the uptake of C-ITS is expected to differ from application to application, several predictions have been made with respect to deployment timelines in different regions.

In 2012 the United States Department of Transportation (USDOT) and Transport Canada requested that the American Association of State Highway and Transportation Officials (AASHTO) conduct a national connected vehicle field infrastructure footprint analysis to identify a vision for C-ITS deployment timeframes for various scenarios (Wright et al., 2014).

In terms of the vision for infrastructure deployment timelines, it was anticipated that by 2040 in the US, up to 80 percent of traffic signal locations will be V2I enabled, up to 25,000 other roadside locations will be V2I enabled, real-time, localised traveller information services will be available on 90% or more of roadways, and next-generation multimodal active traffic management will be deployed system-wide. The vision analysis also anticipates that vehicles with embedded DSRC would begin to be deployed by around 2020 and, even under the most aggressive '1-year mandate' scenario (where 100% of new vehicles from a certain model year are all equipped) it would take 20 years for 90% or more of the vehicle fleet to be equipped with connected vehicle technology (Figure 2.3).

The USDOT has also proposed to create a new Federal Motor Vehicle Safety Standard (FMVSS) mandating that new light vehicles sold in the US be equipped with DSRC. This FMVSS was made available for public consultation in January 2017 and projects that 100% of the fleet could be DSRC radio equipped by 2023.

Figure 2.3: USDOT/AASHTO vision estimates of connected vehicle population across time



Source: Wright et al., (2014)

The European Commission have developed a deployment roadmap and deployment strategy for C-ITS in the EU in which it will identify potential solutions to the range of barriers to deploying C-ITS between 2016 and 2020. The Amsterdam Group, a strategic alliance of European road operators and industry, is coordinating the deployment efforts of cooperative ITS in Europe.

Several C-ITS deployment initiatives are also underway in the form of large-scale multi-country demonstration projects:

- **Cooperative ITS Corridor** will run between Vienna in Austria, Munich and Frankfurt in Germany and Rotterdam in The Netherlands. The applications tested include roadworks warning and probe vehicles that will transmit information about current traffic conditions to roadside infrastructure and traffic control centres (see http://C-ITS-corridor.de/data/download/Flyer%20C-ITS-en.pdf).
- **Compass4D pilot project** will deploy cooperative ITS services in seven European cities (Bordeaux, Copenhagen, Helmond, Newcastle, Thessaloniki, Verona and Vigo). Three C-ITS applications (Road Hazard Warning, Red Light Violation Warning and Energy Efficient Intersection) will be piloted for one year using different vehicle types (Toni, 2014).
- **SCOOP@F** will equip 3000 vehicles and 2000 km of streets, intercity roads and highways in Ile-de-France and Bretagne, the Paris-Strasbourg highway, Bordeaux and its bypass and county roads in the Isère. Applications examined include road hazard signalling and traffic information (Fouchal, 2015).

In October 2015, the 16 European vehicle manufacturers who are members of the Car2Car Communication Consortium, announced that they will be working toward the initial deployment of cooperative vehicles as soon as 2019 (Car2Car Communication Consortium, 2015).

Japan introduced C-ITS in the 1990s with the Vehicle Information and Communication System (VICS) that allows drivers to receive real-time road traffic information about congestion and regulation. The VICS systematically collects road traffic information and transmits this to drivers via infrared beacons, FM multiplex broadcasting and radio wave beacons (http://www.vics.or.jp). Japan also implemented the Driving Safety Support Systems (DSSS) in 2011 which uses V2I communications to convey information about traffic control, pedestrian detection and collision avoidance. Toyota also integrated DSSS into their navigation systems in 2011 (UTMS Society of Japan, 2013) and have recently commenced (October 2015) deployment of V2V and V2I applications as part of their 'ITS Connect' safety package in three Japanese models.

VicRoads has noted that the many road safety and traveller information applications are being set up and delivered outside of the C-ITS environment through smart phone applications. For example. Adelaide's 'Addinsight' and Transport for New South Wales 'Speed Advisor' smartphone application provide aftermarket options to receive dynamic in-vehicle warnings. While these applications sit outside the C-ITS environment and are unlikely to part of the final C-ITS environment, the work to build data sets to support these applications is commencing within Australia.

Finally, the Western Australian Office of Road Safety (now Road Safety Commission) has estimated the uptake of C-ITS equipped vehicles in Australia. Using 2017 as year 1, they predict that by 2027 approximately 10-15% of the fleet will be C-ITS equipped and by 2037 around 50-65% of the fleet will be equipped (Main Roads Western Australia, 2015). Austroads has also developed a possible timeline for the introduction of various emerging vehicle technologies (see Figure 2.5).

2.4 Automated Driving Technologies

2.4.1 Identification of Emerging Automated Driving Applications

Automated vehicles are those in which one or more aspects of vehicle control (e.g. acceleration, braking, steering) are performed by the vehicle rather than the driver. Automated driving can potentially improve road safety by supporting the driver in different conditions, such as providing emergency responses in a critical situation or simply taking over some aspects of driving under normal conditions (Trimble et al., 2014). AVs can be autonomous (i.e. relying on in-vehicle sensors) or they can be connected to other vehicles, infrastructure and mobile devices. It is recognised that vehicle connectivity is an important aspect of realising the effective deployment and operation of automated vehicles.

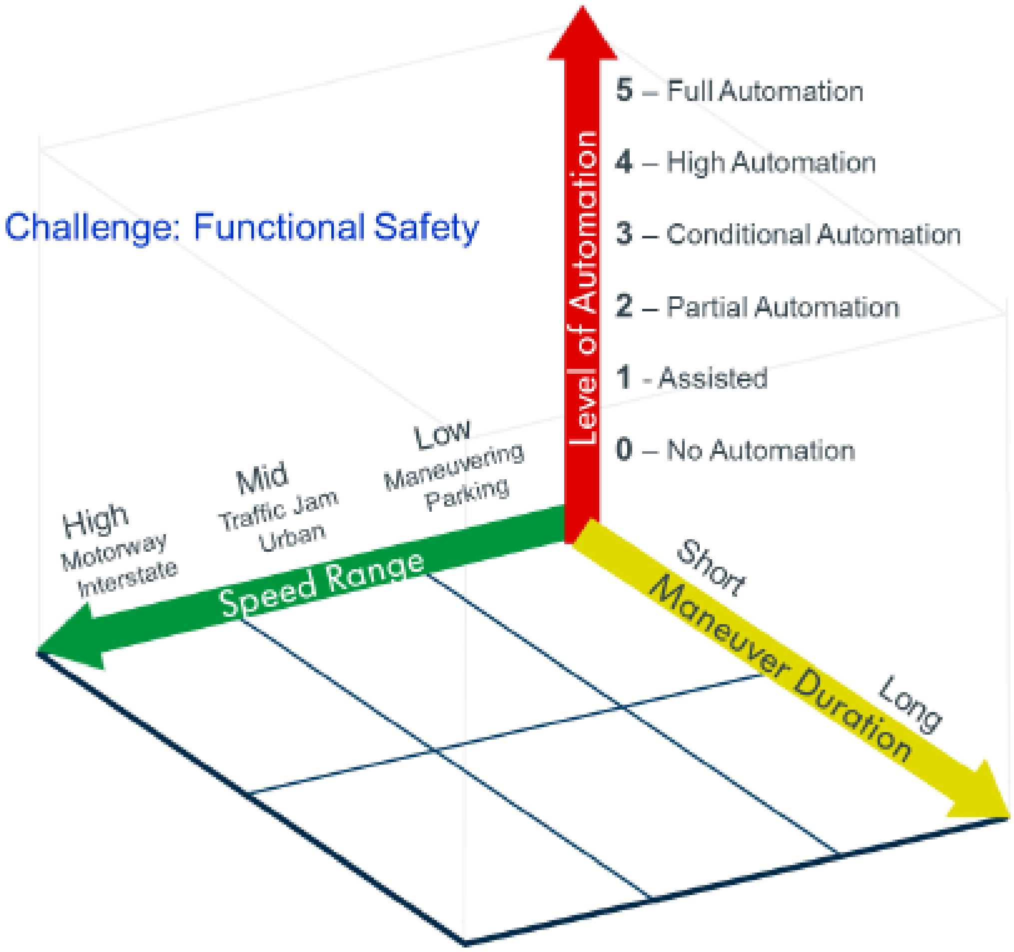
There is a range of different levels of automated driving. A range of agencies have developed classification systems for defining different levels of automated driving, including the National Highway Traffic Safety Administration (NHTSA, 2013), the German Federal Highway Research Institute (BASt; Gasser & Westhoff, 2012) and the Society of Automotive Engineers (SAE J3016; SAE, 2014). While these taxonomies are similar in that they all range from full driver control to full automated driving, they are not identical. The SAE J3016 levels of automation will be used to discuss AV technologies in this review (see Figure 2.1) and the primary focus of this review will be on those automated driving applications considered to be both valuable for safety and forming the foundation for fully automated driving, including:

- AEB;
- ACC (with stop & go);
- LKA (and active steer/lane centre assist).

An increasing number of vehicles currently available on the Australian and New Zealand markets are fitted with a range of applications that enable Level 2 automated driving, including providing automatic longitudinal and lateral control, but that require the human driver to monitor the roadway and be prepared at any time to take back full control of the vehicle. Research into the development of automated driving applications (Levels 3-5) is also underway. It is important to note that the level of automation is not always clear-cut and there is not necessarily an orderly progression through the levels. Some manufacturers are aiming their development focus to skip over Level 3 in favour of Level 4, given that there are a range of human factors concerns surrounding the need for drivers to monitor the system and be available to regain manual control if weather conditions, the type of roadway or other conditions precipitate the need for the system to hand back control to the driver.

Using the SAE J3016 classification, the EU AdaptIVe project has identified four parameters for the further classification of automated driving and parking functionalities: vehicle automation level, vehicle manoeuvre duration, vehicle manoeuvre velocity and road type (see Figure 2.4).

Figure 2.4: Dimensions of automated driving and parking functions from the AdaptIVe project



Source: Bartels, Eberle, & Knapp, (2015)

The European Automobile Manufacturers Association (ACEA) also proposed a similar AV technology classification to the AdaptIVe project that includes automation level and speed (Greven, 2015). However, rather than manoeuvre duration and road type, they proposed the dimension of environment complexity. Using the ACEA classification, Table 2.8 contains descriptions of several applications for Level 2 and 3 automated driving that are now available or are being developed and trialled.

Table 2.8: Matrix of Level 2 and 3 applications for automated driving.

Environment Complexity	Structured (low)			Complex		
Speed	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Level 2	• Auto Parking Assist	• Traffic Jam Assist	• Highway Assistance • CACC • Truck Platooning		• Supervised City Control	
Level 3	• Auto Valet Parking	• Traffic Jam Chauffeur • Active Traffic Light Handling	• Highway Driving • CACC • Truck Platooning	• Auto Valet Parking	• Traffic Jam Chauffeur • Active Traffic Light handling	• Highway Chauffeur • CACC • Truck Platooning

2.4.2 Estimated Safety Benefits of Automated Driving Technology

One of the most widely anticipated benefits of AVs is their potential to improve road safety and save lives. The leading theory is that AVs will not be vulnerable to the errors, misjudgements, violations, overload and fatigue that affect human drivers and lead to crashes (Lari, Douma, & Onyiah, 2015). Indeed, research which states that approximately 90 percent of road crashes are 'caused' by human errors (Rumar, 1990; Singh, 2015) is often used as a general estimate of AVs safety potential. However, this estimate does not consider levels of automation or that some levels will not be supported for some road types, AV technology functions or the potential for system errors and human errors deriving directly from use of the automation. A more conservative general estimate is provided by Fagnant and Kockelman (2015) who suggested that, based on over 40% of fatal crashes in the US involving some combination of alcohol, distraction, drug involvement and/or fatigue, automated vehicles, that are not affected by such impairments, have the potential to contribute to at least a 40% reduction in fatal crashes.

While is it assumed that AVs will not be crash-free, they are expected to confer significant safety benefits, particularly as the level of automation increases (Wagner et al., 2014). An early estimate by the US Federal Highway Administration predicted that a 50 to 80 percent reduction in highway crashes could be realised with the introduction of highly Automated Highway Systems (AHS) that are dual-mode and capable of operating in AHS and non-AHS lanes (FHWA, 1997). Safety modelling of individual vehicle and platoon based AHS also found that, at speeds of 67 mph, automated vehicles had lower rear-end crash probabilities than manually driven vehicles (Carbaugh, Godbole, & Sengupta, 1998). More specifically, the probability of a rear-end collision was 0.87 for typical un-alerted manual drivers and 0.028 for automated individual vehicles. In addition, while the probability of a rear-end collision for automated platooned vehicles was higher (0.37) than for individual automated vehicles (0.015), the expected severity of the collision was lower.

However, highly and even partially automated vehicles have not yet travelled long enough distances for accurate crash reduction estimates to be made. For example, Smith (2012) calculated that an AV would need to travel 725,000 miles unassisted and without an incident to say with 99% confidence that AVs crashed less frequently than vehicles controlled by human drivers. In October 2015, University of Michigan Transport Research Institute (UMTRI) conducted a preliminary analysis of the crash record of three vehicle manufacturers that have conducted automated or self-driving vehicle testing in the US and compared this to the crash records of conventional vehicles in the US during 2013 (Schoettle & Sivak, 2015). They found that the automated vehicles had an almost five times higher crash rate that conventional vehicles (9.1 versus 1.9, respectively) and an injury rate more than four times higher than conventional vehicles (3.29 versus 0.77). The severity of the injuries sustained, however, was lower in the automated vehicles than conventional vehicles and the automated vehicles were not at fault in any of the crashes. The authors highlighted a range of caveats with their findings, including that the distances travelled by automated vehicles is far less than for conventional vehicles (1.2 million miles versus 3 trillion miles); the automated vehicles have been driven in limited conditions that are less demanding and are not representative of the conditions experienced by conventional vehicles; and the 95% confidence intervals overlapped so it cannot be discounted that the actual crash rates for automated vehicles are not the same or lower than those for conventional vehicles. Therefore, the potential crash reduction benefits of Levels 2, 3 and higher AV functions remains highly speculative.

However, several Level 0 and 1 automated driving systems, with the potential to be developed into Level 2 systems, have demonstrated safety benefits. Large-scale trials of Intelligent Speed Adaptation (ISA) (L0/1), which automatically alerts drivers or limits vehicle speed when the posted speed limit has been exceeded, have found, for example, that the deployment of a fixed mandatory limiting system to all vehicles in the UK would reduce injury crashes by up to 20% and fatal crashes by up to 37%, while deployment of a dynamic ISA limiting system would reduce injury crashes by 36% and fatal crashes by 59% (Carsten et al., 2008; Carsten & Tate, 2005).

NHTSA (DOT, 2016) estimated that full adoption of DSRC with IMA and LTA would prevent 13-18% of multiple vehicle light vehicle crashes in the US.

The National Transport Safety Board (NTSB) also estimated that, of the 3,491 rear-end crash fatalities occurring in the General Estimates System (GES) database during 2011-2012, up to 2,220 (64%) could have been prevented if the vehicles had been equipped with a forward collision avoidance system (L1) (NTSB, 2015). This estimate assumed a perfect system, capable of providing sufficiently early warnings or initiation of AEB (L1). On its own, Adaptive Cruise Control (ACC) (L1), which, in addition to speed control, automatically maintains an appropriate headway to lead vehicles, has been estimated to be capable of addressing 4-6% of fatal crashes and 13% of severe casualty crashes in EU25 (COWI, 2006). When combined with FCW, ACC was estimated to prevent or mitigate 345 fatal crashes and over 59,000 injury crashes annually in EU27 (Geissler et al., 2012). Finally, a Swedish study found that AEB reduced all striking rear-end crashes, regardless of speed area, by between 35% and 41% (Rizzi, Kullgren, & Tingvall, 2014). Fildes et al (2015) determined an estimate for Australia of 36% (95% C.I. 18-53%). Sternlund et al (2016) evaluated LKA and suggested a 30% reduction for all head-on and single vehicle run-off-road crashes in Sweden (excepting snow-covered roads).

It is important to note that while the introduction of AV technology may reduce many of the risks associated with driving, it may also increase other risks or introduce new risks that could offset the expected safety benefits. These include the risk of a system rather than a driver error, an increase in travel which in turn increases exposure to risk and problems with Levels 2 and 3 automation, where drivers are required to monitor the environment (L2) or the automated system (L3) and to respond to requests to take back control (L3). The human factors issues associated with AV technology are summarised in Section 2.5.

2.4.3 Predicted Deployment Timelines for Automated vehicles

The uptake of AV technology is expected to differ across the various levels of automation and the level of physical and digital infrastructure available on various roads to support the higher levels of automation. Technical (i.e. current sensor technology challenged by poor weather conditions) and regulatory/legislative issues (i.e. note that Australian road transport law assumes a human driver[5]) are also expected to impact deployment timelines, although a discussion of these are beyond the scope of this report. Several predictions have been made with respect to AV deployment timelines. One of the most general predictions estimates a limited availability of highly AVs or self-driving vehicles by 2020, with wide availability to the public by 2040 (Lari et al., 2015). This timeline is in line with other predictions. Levinson (2015) predicted that (NHTSA) Level 3 automation will be available by 2020 (e.g. truck platooning), while (NHTSA) Level 4 full automation available in *new* cars by 2030 and in *all* cars by 2040. Members of the Institute of Electrical and Electronics Engineers (IEEE) estimated a more conservative uptake timeline, suggesting that up to 75 percent of all vehicles will be automated by 2040 and that there will be dedicated lanes for AVs to travel in (IEEE, 2012).

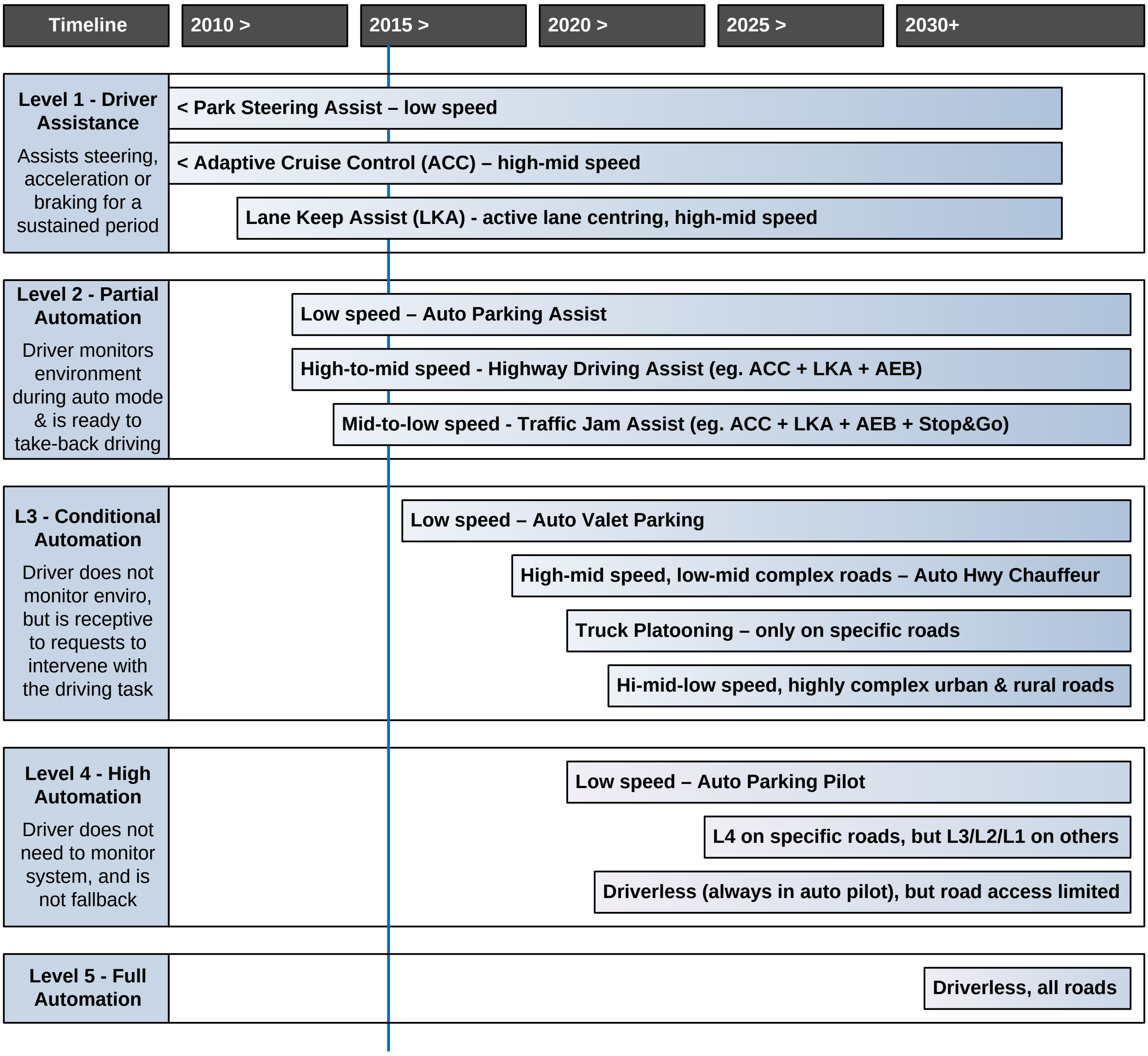
Ford's Blueprint for Mobility presents their estimates for AV uptake (Ford Motor Company, 2014). They estimate that limited automation for parking and assistance in slow moving traffic (e.g. active park assist, ACC) would be available sometime between 2012 and 2017, semi-automated vehicles would be available between 2017 and 2025 and fully automated vehicles would be deployed between 2025 and 2030. Other vehicle manufacturer's estimates are similar, with General Motors, Nissan and Continental AG predicting that Level 4 and 5 automated driving will be available in the 2020 to 2025 timeframe (Trimble et al., 2014).

Finally, an estimated roadmap for the deployment of C-ITS and Level 2 to 5 AV technologies on Australian roads has been developed based on research and discussions with C-ITS and AV experts from around the world (see Figure 2.5).

[5] The National Transport Commission review of Australia's road transport law concluded that a complete reading of Australia's road rules assumed that a human driver is present to satisfy the intent of the rules. It is currently the subject of a reform program across Australia's state and territory road law.

The introduction of Automated Driving systems means this basic principle is no longer compatible with advanced vehicle technologies

Figure 2.5: Possible C-ITS and AD deployment timelines for Australian and New Zealand roads



Note: Levels of automation from SAE J3016.

Source: Austroads, personal communication.

2.5 Human Factors Issues with C-ITS and Automated Driving

It is possible that the potential safety benefits of C-ITS and AVs may be undermined by a range of human factors issues if not properly addressed. C-ITS and automation will change the driving task, either by providing additional sources of information or by automating some to all aspects of the driving task. This can lead to changes in driver behaviour, some of them not intended by the system designers. In road safety, the term ‘behavioural adaptation’ (see e.g. Garrott and Mazzae, 1999) is typically used to refer to the unexpected or unintended behavioural changes that appear in response to the introduction of a change in the vehicle or road environment that may influence the predicted safety benefits of this change. The anticipated behavioural adaptation issues that can arise with the introduction of C-ITS and AVs are discussed briefly below. Many of these issues are common across both C-ITS and AVs.

2.5.1 Driver Overreliance (Automation Complacency)

Over-reliance, also called 'automation complacency' (Parasuraman, Sheridan, & Wickens, 2000) or 'delegation of responsibility' is an important human factors issue when introducing C-ITS and automation. Over-reliance occurs when drivers delegate full responsibility for driving tasks to the system (regardless of whether the system is intended to assume full responsibility or not), or delegate responsibility for other driving tasks that the system was not designed to address. Over-reliance can occur because of a loss of vigilance or drivers misunderstanding the functionality and limitations of the technology and creates problems when the system is no longer active, such as when drivers use a non-equipped vehicle or when drivers are required to regain vehicle control.

Over-reliance has been observed in a number of ISA studies, where drivers, for example, forget to change speed upon entering a different speed zone when the ISA is no longer active (Comte, 1998; Hjälmdahl & Várhelyi, 2004). Numerous instances of over-reliance on ACC systems have also been reported. For instance, drivers were observed to brake later in response to a braking lead vehicle when using ACC (Hoedemaeker & Kopf, 2001; Rudin-Brown & Parker, 2004) and some drivers failed to reclaim vehicle control and collided with a lead vehicle when the ACC failed without warning (Stanton, Young, & McCaulder, 1997). However, drivers are able to effectively assume control from ACC in critical braking situations if provided with a warning (Lee et al., 2008).

Educating drivers about the capabilities and limitations of C-ITS and AV technologies and providing timely warnings when the system moves outside of its performance envelop can help reduce the risk of over-reliance.

2.5.2 Adoption of Risky Driving Behaviours

If C-ITS and AV technology are perceived as providing safety benefits, they can change drivers' perception of driving risk and encourage risky driving behaviour. Drivers may adopt risky driving styles to adjust their level of preferred risk, to experiment with the system, or to improve their mobility and compensate for factors such as lost time due to lower speeds created by some systems. When using ISA, for example, drivers compensated for slower overall speeds by driving faster on roads where ISA was not active, or in situations that warranted lower speed such as when turning or in poor weather (Comte, 1998; Hjälmdahl & Várhelyi, 2004).

The period of mixed traffic, where automated vehicles will share the road with non-automated vehicles, may also present issues in terms of the behaviour of drivers of non-automated vehicles. Issues may occur for example, if drivers of non-automated vehicles expect automated vehicles to behave in the same (sub-optimal) manner as non-automated vehicles and this expectation is not met (van Loon & Martens, 2015). In a preliminary analysis of the crash rates of automated vehicles, Shoettle and Sivak (2015) found that although automated vehicles had an almost five times higher crash rate than conventional vehicles, none of the crashes were the fault of the automated vehicles. Such findings suggest that the drivers of conventional vehicles may have issues or uncertainty reconciling how they expect automated vehicles to behave.

Alternatively, drivers of non-automated vehicles may adopt similar behaviours to automated vehicle platoons which are incompatible with safe manual driving. For example, in a simulator study by Gouy et al. (2014), participants driving non-automated cars were observed to adopt similar following behaviour to automated vehicle platoons by driving at reduced time headway to lead vehicles.

2.5.3 Driver Workload

A common claim made regarding C-ITS and AV technologies is that they will reduce the demands placed on the driver and thereby improve performance and safety. However, an attempt to reduce workload through driver support systems can potentially increase driver mental workload as these systems add information which must be monitored by drivers. Humans are poor at monitoring tasks (Bainbridge, 1987) and research has shown that monitoring systems is stressful and can cause high levels of workload (Hancock & Parasuraman, 1992; Parasuraman, 1987). Educating drivers about system function and optimal system design (e.g. reliable, well-timed and well-integrated warnings) can help reduce the risk of driver overload, particularly when multiple systems are introduced in the vehicle or drivers are required to continuously monitor a system and be ready to regain control (i.e. Level 2 automation).

The introduction of C-ITS and AV technology can also reduce processing demands under certain circumstances to the extent that drivers experience mental underload and a loss of vigilance. A loss of vigilance can lead to a host of problems, including reduced situation awareness and an inability to cope with a sudden increase in demand, as can occur during a system failure or the occurrence of a safety-critical event outside of the capacity of the system, where drivers need to take back vehicle control (Stanton et al., 1997; Ward, 2000).

A challenge for C-ITS and AV designers is to provide systems that maintain an optimal level of driver workload, where drivers are not overloaded in critical situations and sufficiently stimulated to remain ‘in the loop’. The level of workload experienced by drivers is likely to differ substantially across automation levels, where the role of the driver shifts from manual control (Levels 0 and 1) to the role of monitoring the driving environment and automated system status (Levels 2 and 3). Issues with workload may be especially apparent with Levels 2 and 3 automation, where drivers are required to monitor the environment (L2) or the automated system (L3) (see, for example OICA, 2015). At Level 3, driver underload and loss of situation awareness may become problematic. As noted above, humans are poor at monitoring systems, which could interfere with the driver’s ability to successfully resume manual control when issued with a system handover request. The removal of the need for drivers to monitor the driving environment could also lead to a loss of situation awareness, further impacting the success of a handover request.

2.5.4 Driver Distraction

C-ITS can be a distraction risk if they startle the driver with alerts, if they present confusing, excessive or false alerts or they divert the driver’s attention away from safety-critical events; that is, if they draw the driver’s eyes away from a hazard in the road toward an in-vehicle display. A challenge for C-ITS developers is to design these technologies so that they direct a driver’s attention to essential information or events, but do not distract the driver from critical events or delay drivers from taking appropriate action.

It is also possible that the introduction of C-ITS and AV technology may lead drivers to engage more frequently in distracting activities while driving, because the systems automate part of the driving task, freeing up the driver’s attention (Smiley, 2000). Indeed, Jamson et al. (2013) found that drivers became more heavily involved in secondary entertainment tasks when driving a highly automated vehicle compared to when driving in manual mode. Thus, C-ITS, automation and distraction could present a vicious cycle, where spare attention created by increased reliance on the systems could encourage engagement in distracting tasks, while distracting tasks may, in turn, further encourage over-reliance on automated systems.

2.5.5 Driver Acceptance

Acceptance of C-ITS and AVs by drivers is a critical factor influencing the successful uptake of these technologies and their effectiveness in improving road safety. A failure of drivers to accept a technology can lead to them not using the system in the manner intended, or failing to use it at all. Acceptance is closely linked with driver trust – if drivers do not trust that a system is reliable, safe, secure and effective, then they are unlikely to find it acceptable. Research has also generally found that acceptability of ITS appears to decrease as the level of automation increases (Burnett & Diels, 2014).

Based on research from the US Connected Vehicle Safety Pilot Program, public acceptance of V2V collision avoidance technology appears generally positive. Around 85 percent of drivers who experienced these systems as part of the driver clinics were positive about them, finding the alerts effective, intuitive and desirable. However, results from a 6 month follow-up with drivers in the Safety Pilot Model Deployment found more mixed responses to the technology, with many drivers giving neutral responses and focussing on the number of false alerts issued by the systems (Harding et al., 2014). In a review of human factors studies of vehicle automation, Trimble and colleagues (2014) reported that the percentage of consumers who are favourable toward having an automated vehicle is between 18% and 49%, indicating that there is still some way to go to build consumer confidence in automation.

The acceptability of C-ITS and AVs can be enhanced if drivers are informed of the safety benefits of the technology, if drivers find them useful and usable, if they are confident that the systems are reliable, cost-effective, secure from cyber-attacks and that their privacy will be protected.

2.5.6 Driver Trust

Trust is one of the most important cognitive characteristics that determine the appropriate use of automation and driver support systems (Lee & Kantowitz, 1998). Drivers can experience issues with ‘overtrust’ and distrust (Lee & See, 2004). Overtrust occurs when the drivers’ trust in the system exceeds the actual capabilities of the system. This can lead to system misuse if the driver attempts to use the system in situations that are outside of the systems operating abilities. Distrust occurs if the driver believes that the capabilities of the system are less than they are and can lead to non-use. False and poorly timed warnings or system intervention, in particular, can undermine driver trust in a system (Lee et al., 2002). With appropriate design and driver training, system developers should aim to achieve calibrated trust, where the driver’s level of trust in a system is in line with system capability.

2.5.7 Loss of Skill

Automating parts of the driving task may lead to a loss of skill and this problem is likely to increase as the level of automated driving increases (Toffetti et al., 2009). If humans do not perform a task for a period, they begin to lose the skill to perform that task effectively even if they could perform it to a high standard previously. Loss of skill can lead to problems in the event of automation failure where the driver is required to regain manual control. This requires a skilled driver who needs to perform the manual control tasks as well as the automation and often under time pressure. A challenge for system developers, manufacturers and governments will be designing automation and implementing policies to ensure that drivers can maintain a minimum level of driving skill (i.e. by requiring intermittent manual control) or removing the need for drivers to intervene at all in the driving task.

2.5.8 Regaining Manual Control

Until vehicles become fully automated (Level 5) and no longer require any human input, even in the event of a system failure, the driver will need to be prepared to reclaim manual control of the vehicle under certain conditions. A whole host of factors including loss of skill, loss of situation awareness and overreliance can cause issues with drivers regaining control of an automated vehicle. Reduced situation awareness, for example, has been associated with a delay in appropriate braking when a failure in ACC was encountered (Rudin-Brown & Parker, 2004; Young & Stanton, 2007). Research has also shown, however, that drivers are able to effectively assume control of the vehicle from ACC in critical braking situations if provided with a warning that the system has exceeded its braking capabilities (Lee et al., 2008). Norman (1990) has also suggested that automated systems should provide real time communication to the driver about its status to ensure that any system failures are not a complete surprise to the driver and the driver can take effectively regain control.

2.5.9 HMI Issues

A range of Human Machine Interface (HMI) issues are required to be resolved to ensure that C-ITS systems and AV technology are usable, effective and do not pose an undue level of workload or distraction on drivers. As more systems are introduced into vehicles, integration, particularly of aftermarket systems, will become increasingly important as drivers will need to be able to distinguish between information from multiple systems and the systems will need to communicate with each other to ensure that any alerts or information provided are prioritised so as to not overload and confuse the driver with multiple sources of information at once (Kantowitz & Moyer, 2000). In a related issue, it is important that the design and function of C-ITS and AV technologies are consistent across vehicles and regions so that drivers do not have to learn multiple systems and warning types and their vehicle can function regardless of the region they drive it in. Finally, the timing of warnings and alerts need to be optimised so that false alarms are kept to a minimum and drivers have enough time to react successfully to the information. Information provided too early or inappropriately (i.e., false alarms) can result in loss of trust, distraction, ignoring the alert, or to drivers shutting down the system entirely (Lee et al., 2002).

3. Stakeholder Consultations

Eight C-ITS and AV technology research and policy stakeholders from the UK, US and Europe have been contacted. The consultations were designed to supplement information from the literature review and obtain information on current and upcoming projects that have not been publicly released. The experts were asked to provide information about current activities in C-ITS and AV research internationally, likely timelines for deployment, and what they see as the key challenges to C-ITS and AV deployment in their respective regions. A summary of the key findings of the consultations is provided below.

3.1 Current C-ITS and AV Projects

The experts provided new or additional details about a range of current C-ITS and AV projects.

C-ITS:

- **Wireless connectivity - ITS Corridor- Data and Services Feasibility Study (October 2015 – June 2016) – UK.**
  The scope of this project covers the provision of C-ITS services along the A2/M2 corridor in the UK with a view to a wider roll out on other motorways. The project aims to identify the key data and services drivers of the connected corridor by understanding what is required by service providers and how this can be matched and prioritised via a connectivity service.
- **C-ITS for The People's Republic of China.**
  The project objectives include: providing support for establishing a policy for the development, implementation of a mobile-communication-based ITS, using V2V and V2I connected vehicle technologies.
- **Secure Cloud-based Distributed Control (SCDC) Systems for Connected Autonomous Cars (2015-2020) – UK.**
  The vision for this project, funded by the Engineering and Physical Sciences Research Council (EPSRC), is to design and validate a novel, Secure Cloud-based Distributed Control (SCDC) framework to enable implementation of safe and robust semi-autonomous functions on future cars in the short term, and fully autonomous cars in the long term.
- **ISA Intelligent Speed Assistance (2015-2016) – London, UK.**
  Transport for London Buses are presently in the process of running a trial of limiting ISA. The ISA equipment has been fitted to every bus on two bus routes within London, and monitoring equipment has been fitted to four buses. The elements being assessed are: the effectiveness of the system, the efficiency of the system (how does this speed control method work in comparison to other speed control measures), the impact on bus timetabling, and the impact on the behaviour of surrounding traffic.

Automated vehicles:

- **GATEway Project** An £8 million project funded by industry and Innovate UK and led by TRL in Greenwich to investigate automated vehicles in the urban environment. The project will test driverless shuttles, autonomous valet parking and automated deliveries as part of the two-year programme, which is just about to commence.
- **Jaguar Land Rover and Engineering and Physical Sciences Research Council (EPSRC) Autonomous vehicle research program** An £11 million project examining the use of radar and video sensing to interpret the environment, road conditions and other road users; how drivers will react to autonomous systems; how systems can be designed to adapt to the personal characteristics of users; investigate how the transition between human control and automated systems can be optimised; how distributed control systems and cloud computing can be integrated with vehicles; and how data from intelligent infrastructure, drivers and automated vehicles can be used to aid interaction.

- **Driving Automated Vehicle Growth on National Roads (DRAGON) – EU (2015-2016)** This project focuses on the role of National Road Authorities (NRAs) in supporting the movement towards high and full automation and realising the benefits and savings that come with it. This project will consider both the general case for NRAs in Europe, as well as focussing on the needs of individual case study NRAs. The aim will be to understand the potential costs, benefits and impacts of automation as a motivation to understand the enablers of, and barriers to, automated driving delivering those benefits to European NRAs.

3.2 Applications with the Greatest Expected Safety Benefits

One of the experts indicated that the safety benefits of C-ITS are currently quite modest as C-ITS is about information to the driver rather than vehicle control. However, the expert stated that more can be expected of V2V and V2I application when these systems can more positively affect vehicle control directly. In the near term, one expert stated they see the greatest benefit in the following technologies; however, in the longer term other C-ITS and AV technologies, when deployed in larger numbers, are also likely to have substantial benefits:

- Intelligent speed advice
- Advance warning of obstacles in the road ahead
- End of queue warning

3.3 Timelines to Deployment

The experts noted that C-ITS is vital for automation development so both are being considered together with respect to deployment, at least in Europe and the UK.

One expert noted that eCall will be the first wide-scale deployment of a C-ITS application in Europe and the UK. Another deployment project in the planning phases in the UK is a C-ITS corridor between the Dover Port and London. The Department for Transport, Highways Agency, Transport for London and Kent County Council are involved and the project may be further developed with European funding. This project will be a pilot and is likely to commence in the next 1-2 years and may be more widespread in 5+ years. One European expert reported that initial deployment of cooperative vehicles would begin as soon as 2019.

In terms of automation, the experts agree that deployment timelines will differ depending on the level of automation and the environment in which the automated vehicles will be operating (i.e. public roads, private test track, highways, or urban roads). The general assumption is that when automated technologies are shown to work reliably, public adoption will happen very quickly. The experts agree that Level 4 automation is where many automotive manufacturers are focussing their development efforts. One expert predicted that Level 4 and 5 automated vehicles will not be operational on a large scale until 2050, as the infrastructure to support the technology in all conditions and locations will not be available until then.

3.4 Implementation Challenges

The experts noted challenges to the wide-scale implementation of C-ITS and AVs that are being experienced, but that are being addressed:

- Several organisations are pushing technology (particularly automated technologies) faster than regulations can manage
- Standards are still not universally agreed to allow vehicles made by different manufacturers to communicate with each other and with the road infrastructure. While interoperability standards have been established at regional level (particularly for C-ITS), work is continuing on global harmonisation.

- Choice of communication technology is still not finalised (The European Telecommunications Standards Institute EN 302 571 will almost certainly change over time, and could support technologies other than DSRC in future)
- The capabilities of current proximity sensor technology (i.e. camera and laser/LIDAR) are restricted during bad weather, such as rain and fog
- Data privacy is a concern (but is being addressed)
- Cybersecurity is a big public concern (but being addressed by manufacturers)
- Determination of public benefit case is not clear
- Business cases (it is not clear who will provide what and where the profit is).

4. Estimation of Safety Benefits

This section focuses on identifying the potential safety benefits of those applications suggested by the literature review as constituting the fundamental components of full self-driving functionality, as well as having the potential to yield significant benefits in reducing serious trauma on the road systems of Australia and New Zealand.

Based on the findings of the literature review, four C-ITS and two AD applications with the highest expected serious crash reduction benefits were selected.

- Cooperative Forward Collision Warning (CFCW): V2V application targeting rear end crashes;
- Intersection Movement Assist (IMA): V2V application for cross-traffic crashes;
- Right Turn Assist (RTA): V2V application for right-through crashes (equivalent to 'Left-Turn Assist' for left-through crashes in left-hand drive jurisdictions);
- Curve Speed Warning (CSW): V2I application addressing single vehicle carriageway departure and head-on crashes on curves;
- Lane Keeping Assist (LKA): automated driving application for single vehicle carriageway departure on straight roads
- Auto Emergency Braking (AEB); automated driving application for prevention of rear end crashes.

Further detail regarding the assumptions made to evaluate the effectiveness of each in this assessment is provided at the start of each individual section. Adaptive Cruise Control (ACC) was suggested by the findings of the review, but was excluded primarily because it is a driver-switchable technology and is therefore may not be available when required. Additionally, the most significant safety benefits arise in emergency braking when its functionality is essentially that of AEB or, for advanced ACC systems, incorporating LKA.

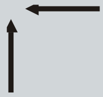
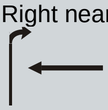
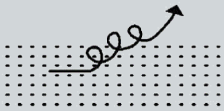
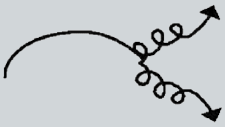
4.1 Methodology

4.1.1 Real World Crash Data

A pool of 817 real world in-depth crash cases collected in Victoria and NSW for the Australian National Crash In-depth Study (Logan et al, 2005) between April 2000 and March 2013 were available for analysis. ANCIS cases are all from crashes where at least one occupant was hospitalised as the result of a crash. Where possible, research nurses conducted a comprehensive interview with participants to understand the circumstances prior to, during and after the crash as well as demographic data. Occupant injuries were documented and coded, the vehicle inspected by crash investigation personnel and the crash site visited within two weeks of the crash date. In all, more than 1500 variables were collected for each crash.

Cases matching the crash types addressable by the technologies under consideration were extracted and a subset chosen at random, with the numbers shown in Table 4.1. In general, approximately half the available cases were targeted for this study, although fewer of the single vehicle carriageway departure crashes were selected due to the large numbers and relative homogeneity of this subset. A total of 817 ANCIS real-world crash cases were available for comparison, of which 250 were of the crash types selected for this analysis.

Table 4.1: Real world case types and numbers selected from ANCIS database

Crash type (DCA)	Description	Number available	Number selected
110	Cross traffic 	21	9
113	Right near 	9	5
120	Head on	33	17
121	Right through 	15	8
130	Rear end 	24	10
170-173	Off path on straight 	97	14
180-183	Off path on curve 	51	9
Total		**250**	**72**

4.1.2 Evaluation and scoring method

A five-level scale was used to score each of the assessments made as shown in Table 4.2. Assessments were made based on expert opinion.

Table 4.2: Scoring system

Score	Estimated effectiveness range	Estimated mean effectiveness	Description
1	0-20%	10%	Highly unlikely
2	20-40%	30%	Somewhat unlikely
3	40-60%	50%	Moderately likely
4	60-80%	70%	Somewhat likely
5	80-100%	90%	Highly likely

For each technology application, the operating parameters were agreed upon to reflect the fact that the precise crash conditions, sensor inputs and system decisions and responses in practice would depend on the implementation by the manufacturer. Individual cases were then subjected to expert assessment to determine the following:

1. Would the application be available for the crash? For V2V applications and AEB, this was generally ‘true’ if the vehicles involved were light passenger vehicles and ‘false’ if one of the crash participants was a truck. For V2I Curve Speed Warning, this was true if the road was a motorway or major highway and false otherwise.
2. Likelihood of the application triggering (or activation of the technology). Expert assessment against the five-level scale was based on whether the pre-conditions were likely to have fallen within the operating parameters of the application. For example, in the case of Intersection Movement Assist, if one of the vehicles was stationary or near-stationary prior to impact it was judged less likely to have triggered the application due to the difficulty in extrapolating a clear time-to-collision.
3. For warning-based applications, assuming triggering of the application and delivery of an appropriate warning, the likelihood of the driver intervening successfully to avoid the crash. The driver interview and medical records were used to assess levels of impairment due to fatigue, drugs, alcohol or distraction and their likelihood rated. In line with Taranto et al (2011), the likelihood of driver intervention was never rated higher than ‘3’ (‘moderately likely’).
4. For applications operating independent of the driver, the likelihood of the system avoiding the crash, given successful triggering. Furthermore, the warning technologies were also assessed hypothetically to provide an indication of their potential benefit should automated intervention become available in the future.
5. Overall effectiveness was calculated by multiplicatively combining points (2) and (3) or (4) above as:

   *[likelihood of successful triggering] * [likelihood of successful avoidance]*

To make the judgements, two evaluators discussed the case circumstances in depth, including the occupant interview, injuries, vehicle and crash site details (with a total of over 1500 variables of information available). The two expert evaluators had a combined more than twenty years of crash investigation and vehicle safety experience between them.

4.2 Crash Scenario Benefits

The mean benefits and benefit ranges in this section are for the random selection of cases drawn from the crash pool and are not necessarily representative of all Australian and New Zealand serious injuries.

The crash scenario benefits assume that each application works independently of each other. So, while a vehicle may be equipped with systems that address similar crash types, a discount on the overall benefit was not incorporated. For example, it is likely that Cooperative Forward Collision Warning and Automated Emergency Braking address similar crash types, albeit with differences in sensing technology (wireless communication, radars or cameras). In this specific example, it is likely that a high proportion of rear-end collisions would be first addressed by the Automated Emergency Braking systems, while Cooperative Forward Collision Warning would address a small additional increase due to the capability of wireless messages to detect a potential crash that a ‘line-of-sight’ system would not have.

4.2.1 Cooperative Forward Collision Warning

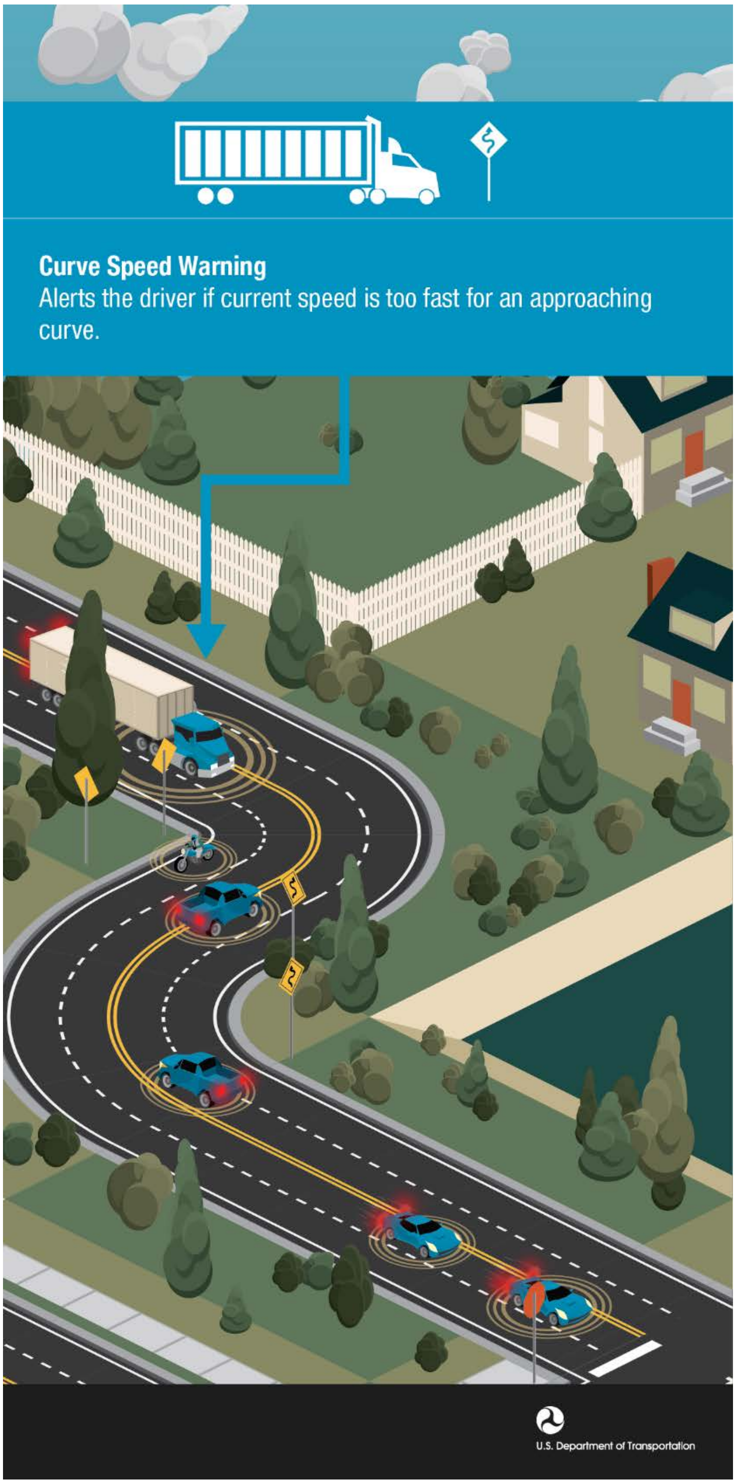
CFCW was assumed to be able to operate for any rear end crash between two vehicles so-equipped. A minimum of 40% overlap was assumed for a high likelihood of successful triggering, with decreasing levels assigned for smaller overlap. Of the 15 cases assessed, 12 were between two passenger vehicles with the other three involving one or more trucks. These were assessed in this section as if both collision partners were light passenger vehicles to maintain the numbers for analysis. Twelve of the 15 occurred in an urban or outer urban environment. CFCW was judged to be either ‘somewhat’ or ‘highly’ likely to trigger 80% of the time, with the remaining three cases involving two cases of narrow overlap (see example photo) and one where the lead (non-case) vehicle abruptly pulled in front of the case vehicle, precipitating the crash. In each of these it was judged that the system would be less likely to trigger. The overall mean likelihood of successful triggering for this sample was calculated to be 77% (range: 68-85%).

Three of the drivers involved (20%) were judged to have been ‘somewhat likely’ to have successfully intervened, the highest level allocated. A further seven were awarded a score of ‘2’ because as the non-case vehicle drivers, there was no evidence regarding their ability to respond (as there was for case vehicle drivers in the study) or the situation gave them much less time to react to a warning. The remaining 33% were given a probable warning response score of 1. One of these drivers had sleep apnoea, another had admitted to ‘falling asleep’ and one was an elderly man who was believed to have sustained a pre-crash medical condition. The overall mean likelihood of successful driver intervention across the sample was calculated to be 34% (range: 30-37%).

Multiplying together the likelihoods of triggering and driver intervention yielded an overall effectiveness of 26% (range: 20-32%), implying that CFCW prevented around one in four rear end crashes in this sample. Kockelman et al (2016) quoted a considerably more optimistic estimate of 70-90% effectiveness for CFCW in conjunction with Cooperative Adaptive Cruise Control.

A hypothetical assessment of a Cooperative Forward Collision Warning system with automated intervention (Cooperative Forward Collision Assist) was also made. Automated intervention was judged to be ‘highly likely’ in five of the 11 cases considered. The average likelihood of successful automated intervention was calculated to be 73% (range: 65-81%). Combined with the trigger likelihoods, the overall hypothetical effectiveness of this automated system on the sample is 56% (range: 44-69%), potentially twice as effective as relying on human intervention.

4.2.2 Curve Speed Warning (V2I)



CSW was assumed to be effective on carriageway departure crashes on curves (head-on and run-off-road) where the entry speed to the corner was likely to be too high for the curvature and prevailing road conditions (under the assumption that wet road detection would be likely built into nearby roadside infrastructure. Most restrictively in the Australian and New Zealand context, it was assumed that the required roadside C-ITS infrastructure would be fitted only on motorway and A-roads.

In total 20 real-world cases were considered (nine run-off-road and 11 head-on on a curve). Of these, only five were thought to have occurred on roads likely to be equipped with suitable V2I infrastructure. Three were main rural arterial highways, one an urban 80 km/h arterial highway and one a rural national freeway route. Nevertheless, the assessment was carried out on the basis that suitable V2I was installed at every crash site.

The role of inappropriate speed, the primary trigger for Curve Speed Warning, was judged from the observed crash severity, weather conditions at the time of the crash as well as direct and indirect evidence provided by the driver. In 10 cases (50%), the likelihood of CSW activated was assessed as ‘somewhat’ or ‘highly’ likely, but 25% of cases were assessed as ‘highly unlikely’ with speed not thought to be a contributing factor. The overall likelihood of successful triggering was calculated to be 60% (range: 54-67%).

The likelihood of successful intervention was scored ‘moderately likely’ for seven drivers (35%) and ‘somewhat unlikely’ for a further ten. Three drivers were judged as being ‘highly unlikely’ to have taken appropriate action, two due to alcohol impairment and one due to sufficiently excessive speed for the conditions that his ESC-equipped vehicle was not able to prevent him leaving the road. Overall, the likelihood of successful intervention for the sample was calculated to be 40% (range: 35-44%).

Overall crash avoidance likelihood for the crashes studied was calculated to be 24% (range: 19-29%).

4.2.3 Intersection Movement Assist

IMA was assumed to be effective on all adjacent direction crashes between vehicles both fitted with the application, with the random sample comprising ten real-world cases (four cross traffic and six right-near). It was also taken that for the system to work, both vehicles would need to be moving to allow path and time to collision to be inferred. The likelihood of effective triggering was reduced if this condition was less certain. Three of the ten cases involved a truck or a bus, but were assessed as if the technology were fitted to all the crash-involved vehicles. Human intervention was evaluated – somewhat conservatively – only on the part of the case vehicle driver.

Triggering was assessed as somewhat or highly likely in 80% of cases and moderately likely in the remainder, yielding an overall average activation likelihood for the sample of 79% (range: 70-88%).

Driver intervention was also found to be relatively successful, with an overall estimated response rate of 52% (range: 46-58%).

The overall crash prevention likelihood for the sample was thus calculated to be 41% (range: 33-51%). Coincidentally, this is of similar magnitude to the real-world effectiveness of speed/red light cameras. Harding et al (2014) predicted that IMA would eliminate 41-55% of intersection crashes.

As was carried out for CFCW, the hypothetical automated intervention scenario was also computed. This yielded an estimated successful intervention likelihood of 90% (range: 80-100%), nearly twice as good as relying on the driver. Combining this with the system activation likelihood gave an overall crash prevention rate for this sample of 71% (range: 56-88%).

Case vehicle

Non-case vehicle

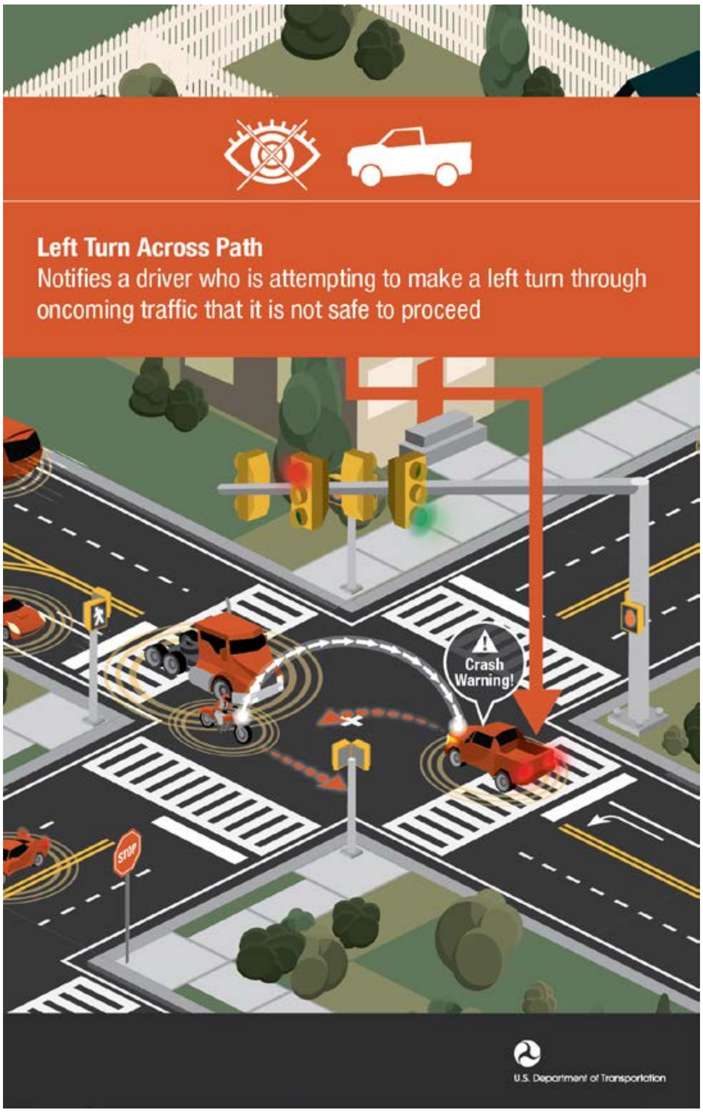
Site for an exemplary IMA case.

4.2.4 Right Turn Assist

RTA was applied to vehicle-to-vehicle right-turn-against serious injury crashes where both were equipped with the technology. While it is likely that commercial RTA applications will use activation of the indicator to initiate monitoring of a potential conflict, this variable was not available from the in-depth data, so this analysis assessed whether the right turning vehicle was believed to be travelling at relatively low speed as a proxy to indicate driver intention to turn right.

A total of 13 cases were assessed, with ten (77%) being judged as highly likely to trigger a Right Turn Assist warning system. Only one case would not have triggered, with the stationary turning vehicle hit from behind, pushing it into the path of the case vehicle. The overall likelihood of system actuation was 76% (range: 68-85%), similar to Intersection Movement Assist.

Successful driver intervention was thought to be probable in all 12 the cases where triggering was feasible, with an overall average likelihood of intervention for the sample of 45% (range: 40-50%). This is a conservative estimate, since lower confidence levels were assigned by default to those cases where the interview was conducted with someone other than the right-turning driver (passenger or non-case vehicle driver).



**Right turn assist in right-hand drive countries*

The overall calculated crash reduction likelihood combining triggering and driver response was calculated to be 34% (range: 27-42%). Harding et al (2014) predicted—for the USA—that Left Turn Assist would eliminate 36-62% of intersection crashes, with a mid-estimate of 49%, somewhat more optimistic than the results of this study.

A hypothetical analysis of an automated version of RTA was also conducted, with every one of the 13 cases judged to have a high likelihood of successful automated intervention and therefore yielding a theoretical overall crash elimination proportion of 69% (range: 54-85%).

4.2.5 Lane Keeping Assist

A Type III LKA system was modelled, capable of keeping the centre of the lane without any steering input from the human driver and assumed to operate at speeds above around 40 km/h and requiring only a centre line and no painted edge delineation. The system was assumed capable of automated operation on roads with some curves, but not on unsealed roads, winding roads or residential streets. Crucially, this assessment assumed that LKA would be continuously active and not rely on driver activation. It should be noted that current production LKA systems do not provide this level of functionality, requiring driver activation, providing only gently corrective steering torque and disengaging on curves.

Of 27 cases assessed (17 head-on, ten run-off-road), 20 (74%) were judged as being likely to have triggered, 11 of these with high likelihood. The cases where LKA was thought to be ineffective (n=7) all involved loss of control by one or other of the drivers involved in the crash, with one occurring on an unsealed road. The overall successful activation of LKA was calculated to be 53% (range: 47-59%).

Successful system intervention to prevent the crash was judged ‘somewhat’ or ‘highly likely’ in 18 of the 20 triggering events, with the remaining two ranked as ‘moderately likely,’ in one case because based on the case evidence driver loss-of-control seemed probable and the other because the passenger stated that he ‘knocked’ or ‘pulled’ on the steering wheel. Overall likelihood of successful system crash prevention was calculated to be 62% (range: 55-69%).

Overall crash reduction likelihood was therefore calculated to be 33% (range: 26-41%).

***Note:** Lane Keep Assist has been categorised into three levels under the European AdaptIve Framework. LKA Type I systems apply a course corrective steering momentum if the vehicle is going to leave the lane. LKA Type II systems apply course corrective steering momentum if the vehicle deviates from the centre of the lane (and therefore still rely on driver input), while Type III systems obviate the need for the driver to apply steering momentum at all.*

4.2.6 Auto Emergency Braking

As with CFCW, AEB is effective against rear end crashes, with this assessment being made on the assumption of AEB operating at all speeds. The same 15 cases were assessed as for CFCW. The three cases involving trucks were left in for this exercise. The sample comprised ten high speed AEB and five low speed AEB cases.

The real-world case evaluation judged that nine of the 15 cases would have been highly likely to have activated AEB, two somewhat likely, three moderately likely and one highly unlikely, the last due to very small overlap between the two vehicles. The overall likelihood for the sample was calculated to be 76% (range: 67-84%).

Successful system intervention was assessed to have been moderately likely in 33% of cases, with the remainder at somewhat likely or ‘somewhat unlikely’, giving an overall successful intervention likelihood for the sample of 55% (range: 49-61%). Allowance was made for the fact that commercial AEB systems try to leave control with the driver for as long as possible and intervention might be relatively late as a result. The overall crash reduction estimated was calculated to be 55% (range: 44-68%).

4.2.7 Summary of real-world assessment

For the samples under consideration, the most effective technology per crash (Table 4.3) was found to be Auto Emergency Braking, estimated to prevent between 44% and 68% of high and low speed rear end crashes, primarily due to it being an automated application not relying on human intervention for successful execution. Based on the sample of real-world crashes assessed, LKA was estimated to prevent between 26% and 41%. Of the warning applications, the two intersection safety technologies, Intersection Movement Assist and Right Turn Assist, each showed potential serious crash reduction abilities in the range of 33-51% and 27-42% respectively for the crash sample under consideration. Curve Speed Warning was less effective with the crashes sampled from the real-world data being more likely to be carriageway departures due to loss of control for other reasons than excessive speed.

Table 4.3: Real-world crash assessment results summary

Technology	Estimated effectiveness range (human intervention)	Estimated effectiveness range (automated intervention)
Cooperative Forward Collision Warning	20-32%	*44-69%**
Curve Speed Warning	19-29%	-
Intersection Movement Assist	33-51%	*56-88%**
Right Turn Assist	27-42%	*54-85%**
Lane Keep Assist	-	26-41%
Auto Emergency Braking	-	44-68%

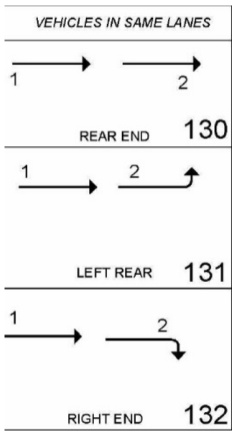
** Hypothetical assessment*

4.3 Projected Benefits for Australia and New Zealand

The real-world crashes were scaled up in accordance with their estimated incidence throughout Australia and New Zealand. Numbers of fatal and serious injury crashes were derived from a database of light vehicle crashes collected for the MUARC Used Car Safety Rating Project (Newstead et al, 2016) for the period 2009 to 2013 inclusive. For Australia, crash type codes (such as DCA, RUM, etc.) were only reliably available for NSW, Queensland, Victoria and Western Australia so the dataset was scaled up based on these four jurisdictions representing approximately 84% of light vehicle serious injury. In total, there were 19874 estimated FSI crashes on average per annum in Australia and 1781 in New Zealand over the period.

The assessments made in this section assume that the applications under study are fitted to 100% of the light vehicle passenger fleet and the benefits quoted are therefore an indication of the maximum possible available with current serious injury numbers and for each technology in isolation. The benefits from combining applications will be additive for those operating on different crash types, with the benefits reduced slightly for those with some overlap.

4.3.1 Cooperative Forward Collision Warning



CFCW was assumed effective on same lane rear end crashes. Among light passenger vehicles, these average 2730 per annum throughout Australia (14% of all Australian FSI crashes) and 80 in NZ (4.6% of NZ FSI crashes), of which around three-quarters (77%) are simple rear end impacts (DCA 130). In the ANCIS dataset, these three crash types comprised 8.5% of the cases, with 81% of these being simple rear end crashes. Based on the results of Section 4.2.1, it was estimated therefore that CFCW has the potential to prevent approximately 700 serious injury crashes annually (range: 560-870) in Australia and 20 (range: 15-25) in NZ.

4.3.2 Curve Speed Warning (V2I)

Serious injury crashes on curves (both head-on and run-off-road) number around 2410 per annum in Australia (12%) and 400 in NZ (23%); in the ANCIS dataset, the proportion is 17%. It was assumed for this study that the necessary C-ITS infrastructure would be installed on only on roads of motorway and high standard arterial, making up an estimated 15% of curve-related FSI crashes across Australia and New Zealand. Consequently, the results of Section 4.2.2 suggested that around 95 FSI crashes per annum (range: 75-115) might be prevented in Australia and 16 (range: 12-19) in NZ.

4.3.3 Intersection Movement Assist

The benefits of IMA were assumed to apply to all adjacent direction crash types, although only cross traffic and right near types were trialled in the real-world cases. These two specific types comprise almost 85% of adjacent direction FSI crashes in Australia and 91% in New Zealand. In total, all adjacent direction FSI crashes numbered 2880 annually in Australia (15%)—with a similar proportion in the ANCIS dataset—and 12% of NZ FSI crashes (215 annually). The estimated effectiveness calculated in Section 4.2.3 leads to a projected reduction in adjacent direction intersection serious injury crashes of approximately 1190 (range: 940-1470) in Australia and 90 (range: 70-110) in New Zealand.

4.3.4 Right Turn Assist

RTA targets another intersection crash type, that of right-turn-against collisions, with a fatality and serious injury crash pool of 1940 per annum (10%) for Australia and 130 annually in New Zealand (7.3%). with a proportion of 7.5% in the ANCIS dataset. Based on the estimated effectiveness from Section 4.2.4, the estimated annual savings in SI crashes are 665 (range: 525-825) in Australia and 45 (range: 35-55) in New Zealand.

4.3.5 Lane Keeping Assist

Lane departure fatal and serious crashes (either head-on or run-off-road) comprise 32% of the total in Australia (6370 per annum) and 40% in New Zealand (715 annually). Allowing for an estimated 15% on residential streets and unsealed roads (where LKA is unlikely to function), the analysis in Section 4.2.5 indicates that advanced LKA systems have the potential to prevent about 1790 SI crashes (range: 1420-2210) per annum in Australia and 200 annually in NZ (range: 160-245).

4.3.6 Auto Emergency Braking

The combination high and low-speed AEB, as assessed, influences the same crash pool as CFCW, only with a greater level of effectiveness. It was estimated that on the pool of 2730 FSI crashes (80 in NZ), approximately 1500 might be avoided annually (range: 1200-1870) in Australia and 45 (range: 35-55) in New Zealand according to the effectiveness estimates derived in Section 4.2.6. Note that this assessment only considered vehicle to vehicle crashes, with pedestrian AEB not evaluated in this study.

4.3.7 Summary of Australia and New Zealand-wide benefits

It should be noted again that the benefits quoted in the preceding sections and summarised here assume that 100% of the light passenger fleet are equipped with both the application in question, as well as the required roadside infrastructure in the case of V2I applications. Benefits are quoted based on average numbers of fatal and serious injury crashes across Australia and New Zealand for the period 2009-2013.

Australia

The application with the greatest potential for preventing fatality and serious injury in Australia is Lane Keeping Assist, estimated to eliminate up to 11% of all FSI crashes throughout Australia (up to 35% of the targeted crash types). Auto Emergency Braking is also predicted to be very effective, preventing up to 1865 FSI crashes annually with the effectiveness estimate of 44-68% slightly higher than a recent evaluation by Fildes et al (2015) that estimated a 95% confidence interval of 18-53%. Intersection Movement Assist, with the second largest FSI crash pool and high effectiveness, was estimated to prevent up to 1470 FSI crashes annually. Cooperative Forward Collision Warning and Right Turn Assist showed similar benefits, each estimated to prevent around 500-800 fatal and serious crashes per annum. Curve Speed Warning, was estimated to prevent between 75 and 115 FSI crashes annually Australia-wide.

Overall, a simple estimate of the cumulative benefits for the whole light passenger vehicle fleet from a full package of these technologies can be made by summing the individual contributions from each, opting for the inclusion of AEB in favour of CFCW, since these two nominally act on the same FSI pool. The range of potential FSI crash savings is therefore approximately 4100-6500 (equating to 4900-7800 fatally and seriously injured persons), which is between one fifth and a third of current fatal and serious injury levels. This could equate to a road toll reduction of between 240 and 375 compared with current day levels.

New Zealand

Advanced LKA also demonstrates significant potential to prevent serious road trauma in New Zealand, eliminating up to 245 FSI crashes annually, representing 14% of all current FSI crashes. Intersection Movement Assist could prevent up to 110 FSI crashes each year and Right Turn Assist up to 55 FSI crashes annually. Rear end crashes, constituting under 5% of FSI crashes in New Zealand compared with 14% in Australia, reduce the aggregate effectiveness of AEB, with up to 55 FSI crashes prevented annually. CFCW and CSW are estimated to prevent up to 25 FSI crashes each.

An estimate of the potential cumulative benefits in New Zealand suggest that 310-485 FSI crashes could be prevented annually (370-580 fatally and seriously injured persons), potentially equating to a road toll reduction of 60-95 over present day levels.

Table 4.4: Projected benefits throughout Australia and New Zealand

		Australia		New Zealand	
Technology	**Estimated effectiveness range**	**Total annual FSI crash pool**	**Estimated FSI crashes prevented**	**Total annual FSI crash pool**	**Estimated FSI crashes prevented**
Cooperative Forward Collision Warning	20-32%	2735	515-805	80	15-25
Curve Speed Warning	19-29%	360	75-115	60	10-20
Intersection Movement Assist	33-51%	2880	940-1470	215	70-110
Right Turn Assist	27-42%	1945	525-825	130	35-55
Lane Keeping Assist	26-41%	5415	1415-2210	605	160-245
Auto Emergency Braking	44-68%	2735	1195-1865	80	35-55

5. Assumptions and Limitations

There are clearly several key assumptions underlying this analysis. The primary purpose of this study was to make high-level estimates of the potential serious trauma savings on Australian and New Zealand roads from the implementation of a selection of technologies. To do this most accurately, not only do the potential outcomes need to be evaluated at individual crash level, but detailed modelling at system level would need to be undertaken to establish the nature of the fleet-level effects as applications propagate into the light passenger vehicle fleet as well as to other segments. These include light and heavy commercial vehicles and even V2X technology for pedestrians and cyclists. The following is a list of key assumptions and limitations for each set of applications:

5.1 Automated Driving

It is recognised that highly automated driving will essentially be enabled by an automated driving system, which employs a range of sensors, computers, algorithms and actuators, to enable a vehicle to sense its environment (including object and event detection, and navigation) and automate the driving task (including steering, acceleration and braking. Cooperative ITS applications, while not essential to automation, could expand the performance potential of automation by improving the ability of the vehicle to sense traffic scenarios in circumstances where on-board sensors cannot. The overall benefits will be considerably more than the benefits afforded by individual applications, however estimating the magnitude of these benefits, both in the long term as well as through the decades-long adoption phase, was beyond the scope of this study.

5.1.1 Lane keep assist and AEB assumptions and limitations

- Current lane tracking systems predominately utilise camera-based systems for positioning within a lane, and may also use radar sensors to detect other nearby vehicles. Camera-based systems look for the contrast difference between line markings, road edges or potentially other infrastructure or vehicles to position the vehicle. For this study, an advanced system requiring a single centre line was modelled although it is noted that some current systems require line marking on both sides of the lane.
- Lane keeping system performances would be limited by the absence of visible lane markings (such as due to poor maintenance, or on unsealed roads). Limitations of the most advanced lane keeping and automated emergency braking systems still include:
  - dirt on the sensors or anything else covering the sensors
  - poor visibility, e.g. due to fog, heavy rain, snow or spray
  - narrow vehicles, e.g. motorcycles or bicycles
  - lane width e.g. the road has very wide lanes, or the road has narrow lanes. (Mercedes GL owner's manual, http://www.mersuv.com/mbread-329.html, retrieved 19 July 2017)
- Lane keeping systems can be deactivated by the driver. Furthermore, some lane keeping systems require the driver to activate the system on vehicle start-up. It was assumed in the study that driver's consistently use the advanced driver assistance systems available to them.

5.1.2 Automated Driving at SAE levels 3 and 4

- Automated Driving applications at SAE level 3 and 4 were not included in the in-depth analysis section of the study. There currently are no light passenger vehicles available that are marketed as having automated driving systems capable of level 3 or above.
- Policy and legal challenges are likely to be a barrier to automated driving systems once they reach SAE level 3 or 4 'conditionally' or 'highly' automated. Partially automated systems, such as those that feature adaptive cruise control in combination with lane keep assistance, are referred to as 'driver assistance systems' in Australia and therefore the legal responsibility for the vehicle lies with the driver of the vehicle. This position is currently being reformed by the National Transport Commission in consultation with Commonwealth, state and territory governments. A future regulatory framework for higher levels of driving automation is currently not in place in Australia. (National Transport Commission 2016).
- For emerging SAE level 3 and 4 systems which can achieve some level of self-driving, digital infrastructure is emerging as of significant importance. Dynamic digital mapping can be used to accurately locate a vehicle (positioning) through high definition three dimensional maps, and to assist the vehicle in understanding road attributes which are important for automated driving (speed zones, temporary roadworks, lane closures). Development of commercial high definition maps of Australia's road network is currently underway, however only limited sections have been fully developed to support automated driving trials. (Austroads, 2017)
- In principle, highly automated driving is possible without cellular V2X communication, even for high and full automation. Several demonstration projects have shown highly automated driving is possible with on-board sensing only. However, it is anticipated that many automated vehicle use cases will require cellular communications, and that some applications will also benefit from C-ITS. Given the expanse of the Australian and New Zealand road networks, cellular coverage is currently low compared with more densely populated nations. (Austroads, 2017).
- This study was unable to determine the potential safety benefits of automated driving at SAE Level 3 and 4 beyond inferring results from lane keep assist and AEB technology that is currently available in the market. The study relied on detailed descriptions of how these automated driving applications operate, which were used to predict benefits in real-world crashes. A vehicle equipped with lane keeping assistance, adaptive cruise control (low speed stop-and-go and high speed) and Automated Emergency Braking) can perform the driving task involving lateral and longitudinal control of a vehicle. This is likely to address many of the key crash types that cause road trauma in Australia. It is reasonable to infer that a vehicle capable of SAE level 3 and 4 automated driving would include some of these benefits, but the safety benefit that can be achieved beyond these remains to be seen. At SAE level 3 and 4, enhanced speed compliance and more appropriate travel speed within the context of the road environment is one likely benefit that could be expected at higher levels of automation. Speed assistance systems which control the speed of the vehicle were shown to produce high levels of road safety benefits in the literature review section of the report. SAE level 3 and 4 driving will need to be further investigated when systems emerge in the market.

5.2 Cooperative-ITS

- The key assumption underlying the safety benefits of the vehicle-to-vehicle applications (cooperative forward collision warning, intersection movement assist and right turn assist) was that the deployment of C-ITS had reached a level of trusted and messages. This would allow vehicle manufacturers to confidently include warning applications in their products, and provide warning signals to drivers when messages are received.
- This report assumed that all technical limitations had been resolved which would result in a trusted system. Achieving a high level of trust between vehicle to vehicle messages is likely to require:
  - Enhanced vehicle positioning, either through hybrid systems which complement GNSS positioning with vehicle sensor positioning, or through enhanced satellite positioning (Austroads, 2011)
  - The effective development of standards, and compliance with standards for applications was in place to allow interoperability between C-ITS devices.

  - The development of a security system to ensure the secure exchange of messages across various connected devices, including road side infrastructure, in-vehicle systems, traffic management centres and personal devices (Austroads, 2015)
  - Similarly, it was assumed that driver trust in C-ITS had been established. Concerns around privacy from positioning messages from a vehicle were sufficiently addressed by Privacy legislation in Australia to prevent their misuse and gain driver trust.
- For safety messages that require rapid responses from drivers, communication between vehicles needs to be low latency. Currently, only Dedicated Short Range Communications (DSRC) technology, usually carried over the 5.9 GHz band, has been evaluated and tested in large-scale field operational trials as being able to meet latency requirements for V2V applications. However, field trials are commencing to determine if other systems such as Cellular-V2X and 5G can meet performance requirements. It was assumed that a class license to enable C-ITS on a dedicated radio spectrum (ACMA, 2016) was operational and provided a low latency exchange of messages for V2V applications.
- For systems based on infrastructure-to-vehicle messages, such as curve speed warnings, operating over short range communications, it was assumed that all appropriate road side infrastructure was in place. It was noted that curve speed warning systems could be enabled through map-based driver assistance applications, aided by weather messages communicated through cellular communications. However, the system was modelled on the provision of messages from local infrastructure at the site.

5.3 Interpretation of results across both Connected and Automated Driving

This report has not been prepared to compare current in-vehicle camera and sensor based technology to connected enabled crash warning systems to favour investment in connected driving over automated driving, or vice versa.

While there is overlap in the crash types addressed by V2V, V2I and automated driving, there are a range of crashes that cannot be prevented by current in-vehicle camera and sensor-based technologies alone. This is because V2V employs wireless connectivity that provide 360-degree coverage along with offering the ability to “see” around corners and “see” through other vehicles. For example, AEB addresses rear-end collisions, but relies on a line of sight to vehicles within its sensor range – typically the vehicle immediately in front. A cooperative system (such as cooperative forward collision warning) would offer an enhanced ability to predict heavy braking from vehicles further up the road. By integrating this warning message with a vehicle’s AEB system, increased information is available to the AEB system which may prepare the vehicle and driver for earlier braking.

Ultimately, a combination of both Connected and Automated Driving should be the goal of road safety authorities working to achieve reductions in road trauma in Australia and New Zealand.

6. Conclusions

This study undertook a comprehensive review of C-ITS and automated driving technologies, including summarising safety benefit estimates from the US, Europe and Australia. Potential human factors issues were identified and consultations with key stakeholders undertaken to identify those applications with the greatest expected safety benefits.

Based on the findings of the literature review and consultation phases, an analysis was undertaken using a random sample of relevant crash types taken from the MUARC database of Australian serious injury real world crashes. In general, it was assumed that all participating vehicles were equipped with the necessary technology, including suitably accurate positioning systems, as well as the necessary roadside infrastructure. Expert estimates were then made of the potential effectiveness of the following applications among light passenger vehicles:

- Cooperative Forward Collision Warning (CFCW), V2V;
- Curve Speed Warning (CSW), V2I;
- Intersection Movement Assist (IMA), V2V;
- Right Turn Assist (RTA), V2V;
- Lane Keeping Assist (LKA);
- Auto Emergency Braking (AEB).

Assessment fell on a scale from Low to High with each likelihood category representing a range of effectiveness with a width of 20% for each category.

For the warning-only connected vehicle technologies, IMA was estimated to be the most effective, capable of preventing between 35 and 50% of serious injuries among its targeted crash type of adjacent direction crashes at intersections. RTA was estimated to prevent between 25% and 40% of right turn through crashes, while CFCW and CFCW each were judged to be able to allow the sample of drivers to avoid 20-30% of the respective applicable crash types.

Given the limitations of human drivers responding appropriately to warnings, a hypothetical estimate was also made of the potential effectiveness of the V2V and V2I technologies (except for CSW), should viable systems be available allowing automated intervention through braking, for example. Under this assumption, IMA and RTA each were estimated to prevent 55-85% of their applicable crash types and CFCW 45-70%.

Of the self-contained applications, AEB was estimated to eliminate approximately 45-70% of same direction serious injuries and LKA around 25-40%.

Based on light passenger vehicle crash data for the whole of Australia and New Zealand, estimates of the fatality and serious injury crash pool were used to project the benefits of individual applications in isolation if fitted to all light passenger vehicles. LKA showed the greatest promise, leading to an estimated reduction in fatal and serious injury crashes of 1400-2200 annually in Australia and 160-245 in New Zealand. AEB was estimated to have the capacity to eliminate 1200-1850 same direction FSI crashes annually in Australia, but only 35-55 in New Zealand. Of the connected vehicle warning technologies, IMA was estimated to eliminate 950-1450 FSI crashes (Australia) and 70-110 (New Zealand) annually; RTA 525-825 (Aust.) and 35-55 (NZ); and CFCW 500-800 (Aust.) and 15-25 (NZ). The roadside infrastructure required for CSW was assumed to be fitted only to motorways and high-volume arterials, with this level of infrastructure commitment equating to annual savings of 75-115 fatal and serious injury crashes in Australia and 10-20 in New Zealand.

A range of limitations for each of the technologies were identified, primarily related to the level of digital infrastructure required for them to operate as predicted. In particular, the ready availability of high accuracy positioning and low latency communications and the necessary interoperability requirements were flagged for the connected vehicle technologies. Fewer limitations were recognised for the automated driving applications, reflected in their current rapid levels of take-up in the fleet.

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Appendix A Major International C-ITS Projects

- **CV Pilots Deployment Project (US DOT) (2014 – 2020)** http://www.its.dot.gov/pilots/ & http://www.umtri.umich.edu/our-results/projects/safety-pilot-model-deployment
- **COMPASS4D (2013 - 2016)** http://www.compass4d.eu/
- **Cooperative ITS Corridor** http://www.C-ITS-corridor.de/?menuId=1&sp=en
- **DRIVE C2X (2011 - 2014) (and PRE-DRIVE C2X 2008 - 2010)** www.drive-c2x.eu/project
- **PRESERVE (Preparing Secure Vehicle-to-X Communication Systems) (2011 – 2015)** www.preserve-project.eu/
- **VRUITS (2013 – 2016)** http://www.vruits.eu/
- **Scoop@F (2014 – 2017)** http://www.developpement-durable.gouv.fr/SCOOP-F-Projet-de-deploiement.html
- **The Cooperative Intelligent Transport Initiative (CITI) (2013 – 2015)** http://roadsafety.transport.nsw.gov.au/research/roadsafetytechnology/cits/citi/index.html
- **COOPERS (CO-OPerative SystEms for Intelligent Road Safety) (2006 – 2010)** www.coopers-ip.eu
- **CVIS (Cooperative Vehicle-Infrastructure Systems) (2006 – 2010)** www.cvisproject.org
- **SAFESPOT (2006 – 2010)** http://www.safespot-eu.org/
- **PReVENT (PReVENTive and Active Safety Applications) (2004-2008)** http://www.transport-research.info/web/projects/project_details.cfm?id=20297
- **Japan DSSS** http://www.utms.or.jp/english/system/dsss.html

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